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ABSTRACT

A detailed study of warning signs with flashers in school zones was conducted by the Kentucky Department of Transportation to determine the signs' effectiveness in reducing the speeds of vehicles during times of pedestrian activity. Field investigations were conducted at all of the 120 flasher locations in Kentucky Highway Districts 6, 7, and 9. About 14 percent of the flashers were inoperative, and such problems as nonuniform signing, hidden flashers, deteriorating signs and pavement markings, and poor sight distances were also found. Speed studies were conducted at 48 locations. Average speed reductions were found to be only 3.6 mph during flashing periods. Signs and flashers at high-speed (55 mph) locations increased the potential for intervehicle accidents due to decreased speed uniformity. Crossing guards caused reductions in vehicle speeds to within the 25 mph limit. Speed enforcement, minimal periods of flashing, good sight distance, and proper maintenance of signs and flashers were shown to improve their effectiveness in reducing speeds. (Author/JG)

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ED146676

RESEARCH REPORT

DEPARTMENT OF TRANSPORTATION

BUREAU OF HIGHWAYS

THE EFFECTIVENESS OF SCHOOL SIGNS WITH FLASHING BEACONS IN REDUCING VEHICLE SPEEDS

U.S. DEPARTMENT OF HEALTH
EDUCATION & WELFARE
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JOHN C. ROBERTS
COMMISSIONER
Division of Research
533 South Limestone
Lexington, KY 40508

JOHN C. ROBERTS
SECRETARY

JULIAN M. CARROLL
GOVERNOR

H-3-40

July 18, 1975

MEMO TO: J. R. Harbison
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report No. 429; "The Effectiveness of School Signs with Flashing Beacons in Reducing Vehicle Speeds;" KYP-72-40; HPR-PL-1(11), Part III B

The report submitted herewith, as is evident in the title, addresses a portion of a subject area which has been historically controversial in its evolution. The idea of incorporating flashing beacons with signing in school zones was perhaps intuitively conceived -- not only as a "live" warning but also as an indicator of times when speed regulations would be in effect. There was a time when some held the opinion that speed signs in school zones had to be covered during non-school hours to render them non-enforceable. Now, a clock-type programmer in the flasher circuit, usually pre-set to a repetitive, weekly schedule, together with the additional message, "WHEN FLASHING", on speed-limit signs, tends to relieve drivers of unnecessary constraints but brings expected constraints to bear when necessary.

Driver attitudes toward restrictive speed limits in school zones vary considerably -- this is shown by obedience and compliance statistics. In a 1971 study (Report No. 327) of traffic controls for maintenance work on highways, 20% of the drivers interviewed admitted that they did not respond to signing until it appeared necessary in their own judgement to do so. However, none ignored the signing. Perhaps the presence of a police officer superimposes an additional constraint on the judgement of those drivers who otherwise assume control of the situation. Many drivers assume a degree of permissiveness whether an officer is present or not and customarily and technically violate all speed limits unless headway is restricted.

Obedience and compliance statistics provided the principal basis in this study for evaluating the effectivenesss of flashing beacons. Driver attitudes and other elements of driver behavior were not evaluated. Nevertheless, the statistics reported clearly reveal a significant improvement in obedience associated with flasher installations. Additional beneficial but intangible effects on driver awareness and alertness may superimpose.

Although school children are taught the dangers of street and highway crossing while they are very young, statistics show a high pedestrian-vehicle accident involvement rate in the age range from 5 to 9 years. The statistics cited in the report are not limited to school-zone accidents. School-age children may constitute a high proportion of the pedestrian activity or population and, therefore, be subject to greater exposure. On the other hand, it is generally believed that children tend to make errors in judgement and to be preoccupied at some critical times. They may have difficulty estimating their action time in comparison to the approach time of vehicles or may make delayed decisions and dart across a road or street -- eyes fixed on their objective rather than on an approaching vehicle.

Factors in addition to approach speeds and sight distances, which bear on speed-limit reductions, are: driver reaction time, braking time, stopping distance (especially in wet weather), probability of increasing rear-end collisions, likelihood of bottlenecking traffic, and possible recourses to other alternatives. Speed limits in the order of 25 mph and less are in the range of creep rates for most automobiles, and ultra-conservatism in establishing reduced speed limits is not recommended.

Respectfully submitted,

Jas. H. Havens
Director of Research

JHH:gd
Enclosure
cc's: Research Committee

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16. Abstract

A detailed study of signs with flashers in school zones was conducted to determine their effectiveness in reducing the speeds of vehicles during times of pedestrian activity. Field investigations were conducted at all of the 120 flasher locations in Highway Districts 6, 7, and 9. About 14 percent of the flashers were inoperative. Such problems as non-uniform signing, hidden flashers, deteriorating signs and pavement markings, and poor sight distances were also found.

Speed studies were conducted at 48 locations. Average speed reductions were only 3.6 mph (1.6 m/s) during flashing periods. Signs and flashers at high-speed (55-mph (25-m/s)) locations increased the potential for inter-vehicle accidents due to decreased speed uniformity. Crossing guards caused reductions in vehicle speeds to within the 25-mph (11-m/s) limit. Speed enforcement, minimal periods of flashing, good sight distance, and proper maintenance of signs and flashers were shown to improve their effectiveness in reducing speeds.

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THE EFFECTIVENESS OF SCHOOL SIGNS WITH FLASHING BEACONS IN REDUCING VEHICLE SPEEDS

KYP-72-40, HPR-PL-1(11), Part III B

by

Charles V. Zegeer
Research Engineer

Division of Research
Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Bureau of Highways. The report does not constitute a standard, specification, or regulation.

July 1975

INTRODUCTION

The use of flashing beacons together with signing has become somewhat standard throughout the country to alert drivers to the presence of school children and to regulate vehicle speed in school zones. Yellow beacons, usually two, flashing alternately may be used with both warning signs and regulatory signs. The only regulatory signs related to school zones are speed-limit signs. Both hazard identification beacons and speed-limit sign beacons are intended to operate only during hours when the warning and speed regulations are in effect. The effectiveness of signs and flashing lights in reducing speeds in school zones has been questioned. Many school flashers seem to be ignored on high-speed highways and near schools where pedestrian activity is low. Physical features of the installation and site appear to influence motorist compliance. Factors such as sight distance, presence of crossing guards, width of the roadway, reliability of the flasher, and flasher placement may influence obedience.

The purpose of this study was to determine the effectiveness of flasher beacons in reducing vehicle speeds in Kentucky. Speed measurements were made during flashing and non-flashing periods at 48 locations. The physical characteristics of each site were identified and compared to speed reductions. A large sample of school flashers was inspected to ascertain their condition and operation. This information was helpful in determining the reliability of the beacons in everyday operation.

NEED FOR TRAFFIC CONTROLS IN SCHOOL ZONES

In 1973, the national pedestrian fatality rate for elementary school children (5 to 14 years old) was about five per 100,000 population. Only pedestrians over 65 years old exceeded this rate. Of the 10,500 pedestrian deaths in 1973, about 1900 were elementary school children. An additional 46,000 children in this age group were injured *(1)*.

In Kentucky, pedestrians between the ages of 5 and 9 represent less than 10 percent of the total population but over 16 percent of all pedestrian fatalities. This percentage exceeded all other age groups (Figure 1) *(2)*. Of the 167 pedestrian deaths in 1973 *(2)*, there were 27 child fatalities (5 to 9 years old). In 1973 there were approximately 600 children pedestrians (5 to 14 years old) who were injured in Kentucky by motor vehicles.

Figure 1. Pedestrian Fatalities by Age in Kentucky *(3)*.

TRAFFIC CONTROLS FOR SCHOOL ZONES

The use of flashing beacons in the United States varies among states. Also, variations of speed limits in school zones range from 15 to 30 mph (7 to 13 m/s). As surveyed by Withefield *(cf. 3)*, the most common limit is 15 mph (7 m/s) (42 percent of the states). About 15 percent of the states use the 20-mph (9-m/s) limit; 12 percent use the 25-mph (11-m/s) limit. Several states are considering revising speed limit: for school zones. Maryland's state legislature is considering a bill to lower the limit from 25 to 15 mph (11 to 7 m/s); on the other hand, a study in Tennessee resulted in a recommendation to raise the limit from 15 to 25 mph (7 to 11 m/s) *(cf. 3)*. The types of flashing beacons in use vary as can be seen from the photographs of a regulatory flasher in West Virginia (Figure 2) and a Kentucky flasher (Figure 3). A variety of flashers in combination with a lighted, speed-limit sign is also in use in Kentucky although not as yet widespread (Figure 4).

While regulatory-type signs and flashing beacons are prevalent combinations in school zones, warning-type sings and flashing beacons are also common in some states. The diamond-shaped, yellow "School Zone" or "School Crossing" signs with two flashing lights is used in many urban areas of Kentucky where the normal posted speed limit is at or below 25 mph (11 m/s) (Figure 5). The school-crossing sign (emblem) is also commonly used with a set of flashers; even the advance school emblem was found to carry flashers (Figure 6).

Signs and beacons are often accompanied by roadway markings, as shown in Figure 5. Permissable signs and pavement markings are given in Part VII of the **Manual on Uniform Traffic Control Devices for Streets and Highways** (MUTCD) *(4)*. Many states publish their own manuals on school-crossing standards and regulations. New Mexico and Kansas are examples of such states *(5, 6)*. The Automotive Safety Foundation also has published a safety program for school pedestrians *(7)*.

Figure 2. Regulatory School Sign with Flashers, Huntington, West Virginia.

Figure 3. Kentucky Regulatory School Sign and Flashers.

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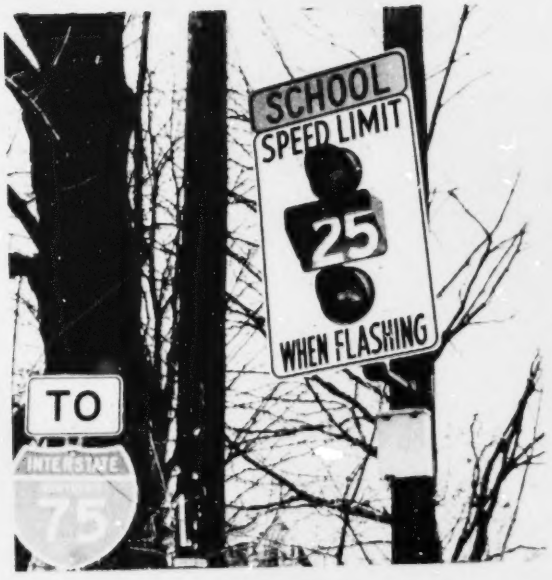


Figure 4. Variation of Kentucky Regulatory School Sign and Flashers.

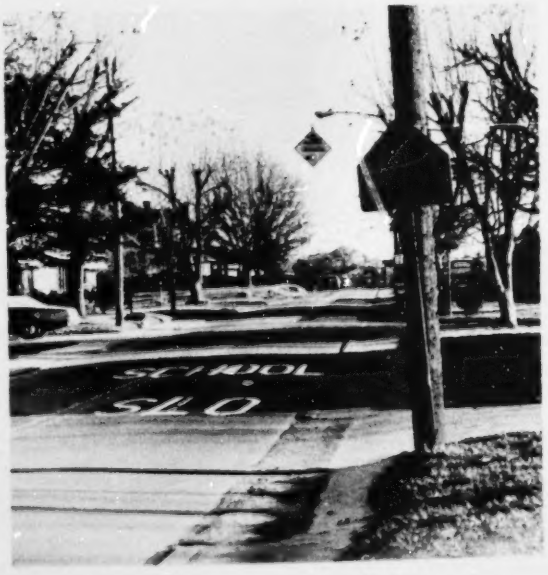


Figure 5. "School Crossing" Sign and Flashers.

Figure 6. School Advance Sign (Emblem) and Flashers.

When flashing beacons are placed back to back above a highway, the point of a school crossing is indicated and a painted crosswalk is usually provided directly below the flashers. When the beacons are separated by several hundred feet (meters), regulatory speed-limit signs are commonly used to control vehicle speeds through the zone. School zones or crossings may provide additional protection for children when a safety patrol or crossing guard is present. A safety patrol usually consists of older children who are designated by the school to supervise street crossings (Figure 7). They have no authority to control vehicular traffic. Crossing guards are adults, usually in uniform, who supervise street crossings and have the authority to regulate vehicular traffic. Local police officers are often used as crossing guards at particularly dangerous locations (Figure 8). Guidelines for the organization and supervision of safety patrols and a guide to the selection, training, and warrants for crossing guards were developed by the American Automobile Association *(8, 9)*.

Traffic signals are helpful at locations having high speeds and volumes and where pedestrian delay can be long. At school areas near signalized intersections, a pedestrian phase may be assigned when turning movements create a hazard for children crossing the street *(7)*. Details of a recommended program for school-crossing protection were developed by the Institute of Traffic Engineers. This program gives guidelines and criteria for implementing various levels of traffic control for school crossings areas *(10)*.

SCHOOL FLASHER PROGRAM IN KENTUCKY

Until 1972, variations of warning and regulatory signs and flashers were installed and maintained by the Division of Traffic of the Kentucky Bureau of Highways. In February 1974, the Kentucky Legislature passed Senate Bill 142 (KRS 189.336) which provides for the use of regulatory "25 MPH WHEN FLASHING" installations where flasher lights were in operation. Thus, all school signs and flashers must exhibit the 25-mph (11-m/s) limit where the speed limit otherwise exceeds 25 mph (11 m/s). The use of warning signs and flashers pertains to school zones where the speed limit is already at or below 25 mph (11 m/s).

The responsibility for establishing warrants for school signs and flashers is assigned to the Division of Traffic which reviews requests for installations from the 12 Highway Districts; monthly each request is investigated in the field by a team of engineers and school personnel. Sight distance, pedestrian volume, vehicular speeds and volumes, and school bus volumes are considered. A list of criteria currently used by the Division of Traffic is provided in APPENDIX A. If approved, school flashers are mounted with either regulatory (SCHOOL-SPEED LIMIT 25 MPH WHEN FLASHING) or warning (SCHOOL, SCHOOL CROSSING, PED CROSSING, or pedestrian emblem) assemblies. All installations include clock-type programming devices providing a weekly cycle (Figure 9); operating schedules for flashers are optimized with respect to activity periods. Flasher assemblies (sign and flashers) are placed back to back at school crossings. Further details are given in APPENDIX B *(11)*.

Maintenance and operation is usually assigned to the highway districts. Some cities agree to maintain them after installation by the Division of Traffic. There are about 20 flashers which were installed by the local urban school authorities. Because of the high cost of flashers (about $1200), most schools on roads or streets maintained by the state request installation by the Division of Traffic.

Figure 7. Safety Patrol Supervising Pedestrians.

Figure 8. School Crossing Guard.

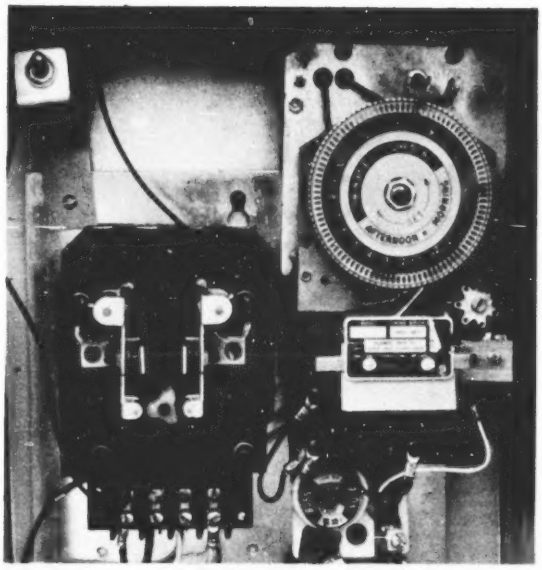


Figure 9. Flasher Clock.

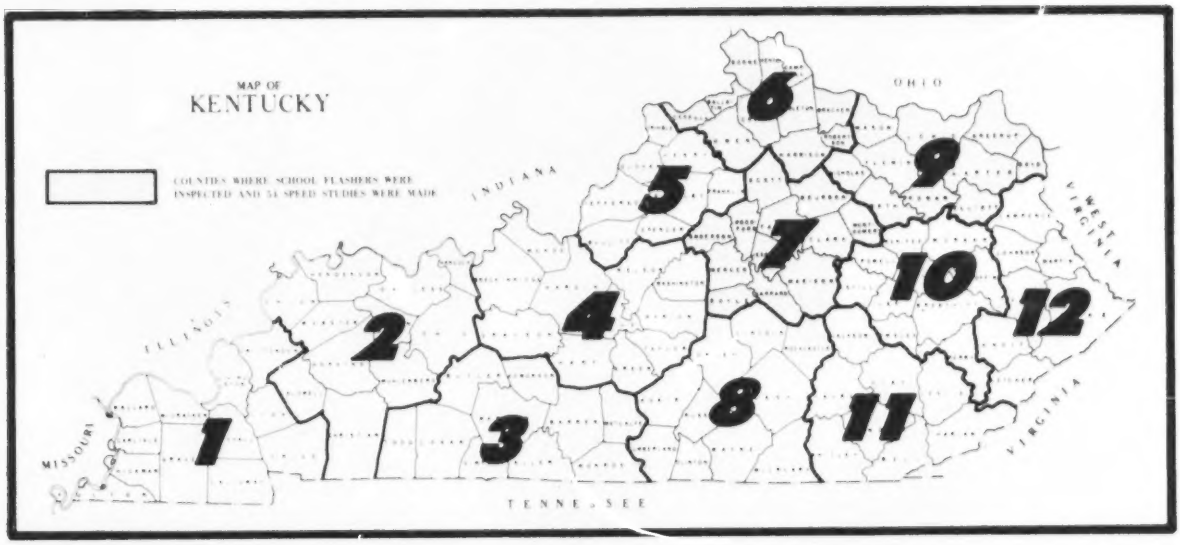
STUDY PROCEDURES

The two major phases of data collection were (1) to inspect a large sample of school flasher locations and document operational problems and (2) to conduct speed measurements during flashing and non-flashing periods at a representative number of locations. The sample locations were in Highway Districts 6, 7, and 9. The three districts comprise 33 counties in central, northern, and northeastern Kentucky, as shown in Figure 10. These districts were chosen because they include urban and rural locations, two-lane, four-lane undivided, and four lane-divided highways, and speed limits ranging from 25 to 55 mph (11 to 25 m/s). The cities included Lexington, Covington, Newport, Ashland, Winchester, Richmond, Paris, Versailles, Nicholasville, and Independence. There were at least three sets of school signs and flashers in each of these cities and a large number of flashers in rural areas and small towns. There were 120 flashers in the three districts (out of a total of 424 school flashers currently maintained by the Bureau of Highways). A statewide listing of the number of flashers by county and district is given in APPENDIX C. The counties with the most flashers are Jefferson with 41, Pike with 14, and Kenton with 13.

Inspection of the 120 school flashers included noting information concerning the highway width, normal speed limit, name of school, flashing times, and other pertinent information that may affect flasher effectiveness. The clocks were checked for accuracy. Flashers were actuated to check bulbs and fuses. In some cases, minor repairs such as cleaning relay contacts and adjusting the clock were made.

Speed measurements were made at flasher locations which had a wide variety of normal speed limits, traffic volumes, pedestrian activity, sight distances, and roadway widths. Also, both warning and regulatory flashers were used as test sites in large cities, small towns, and rural school locations. At each location, a speed meter (radar) was placed in the rear window of a car parked parallel to the road and hidden as much as possible. The car was often parked between two other cars. A newspaper was sometimes used to cover the radar scope so it would not be easily detected by passing motorists. Speeds were measured for about 30 to 45 minutes during flasher operation periods and during off periods. In locations with low volumes of traffic, the sampling plan was to register at least 100 vehicles per period, if possible.

Figure 10. Districts of the Kentucky Bureau of Highways.



At five locations where crossing guards were present during part of the flashing period, vehicle speeds were registered during a flasher-off period, during a flasher-on period without crossing guard, and during a flasher-on with crossing guard. Where driveways and cross streets existed within the school zone, speeds of turning vehicles were not noted. Only speeds of through traffic were recorded. When traffic volumes were high, random sampling was employed. In cases of a caravan of vehicles, a single speed was recorded. School buses were registered only if movement through the school zone was unrestricted. Generally, speeds of vehicles in both directions were taken. While speeds were taken during each test period (during flashing and during off periods), a representative 10- or 15-minute volume count was made during each period. This permitted an analysis of the effect of traffic volume changes on speeds during the two test periods. All information which could have affected speeds in the school zone was listed.

RESULTS OF FLASHER INSPECTIONS

All 120 school flashers in Districts 6, 7, and 9 were inspected to determine how well they functioned. The district, county, route, location, school(s), speed limit, flasher type, and average volumes of daily pedestrians and buses were tabulated for each location. This information is presented in APPENDIX D. Much of this information was extracted from summaries which were completed by each highway district for use by the Division of Traffic.

Another major purpose of the field inspections was to select a representative sample of flasher locations where speed data could be collected. School zones with conditions which may bias the speed sampling were not considered appropriate for speed studies. Such conditions included (1) a crossing only, (2) a single set of flashers in operation, (3) a continual 24-hour flasher, (4) a very low volume (insufficient sample during flashing period), (5) a congested area with a narrow street, (6) a school not adjacent to road, (7) a very steep grade, and (8) a closed school. Since most flashers are located on roadways with posted speeds under 40 mph (18 m/s), not all of the low-speed locations were used. A summary of the 120 locations, as classified by the field investigation, is given in Table 1.

Field inspections permitted discovery of 17 flashers which were defective or malfunctioning. The most common problems were inoperative clocks (seven locations) and burned-out flasher bulbs (four locations). Other problems included deteriorated wiring, disconnected power, and flashers tilted away from desired direction. A list of the 17 defective flashers (about 14 percent) was given to the respective highway districts.

TABLE 1. SELECTION OF SCHOOL FLASHER LOCATIONS FOR SPEED STUDIES

	NUMBER OF LOCATIONS
Speed Studies taken	48
Good Locations for Speed Studies, but Low Posted Speed Limit (25-35 mph)	18
School Zone Begins or Passes Through an Intersection	17
No School Zone (Crossing Only)	12
One Set of Flashers Does Not Exist	6
Continuous Flashing (24-Hour)	6
Very Low Volume Road	4
Congested Area with Narrow Street	3
School Not Adjacent to Road	3
Very Steep Grade on Road	2
School Closed for Repairs (Stamping Ground)	1
Total	120

The placement and maintenance of most flashers were judged to be good. Flashers were mounted in one of three ways: (1) on posts with no extension arms (Figure 11), (2) with extension arms to place the flasher in more direct view of the driver (Figure 12), and (3) suspended over the highway by cables, particularly over four-lane highways (Figure 13). The flasher at one location was hidden by tree limbs and was barely noticeable at a distance of 100 feet (30 meters) (Figure 14). The flashers at another school were twisted away from the direction of travel so that they were barely noticeable by motorists (Figure 15). Some flashers in urban areas were not particularly evident because they were located amidst commercial signing (Figure 16). The flasher shown in Figure 17 seem to be too remote from the roadway. The flasher signs shown in Figure 18 had badly chipped paint and soon may become difficult to read. Pavement markings tend to deteriorate (Figure 19) before renewal is scheduled. A set of flashers at one school was disconnected from the power lines (Figure 20).

Non-uniform signs were in use at some of the flasher locations. The **Manual on Uniform Traffic Control Devices** prohibits the placement of portable stop signs or any signs with commercial messages. While only a few of these signs were found, a school sign was discovered which had the name of a local bank affixed at the bottom (Figure 21). A portable stop sign was in use during school hours on a major city street (Figure 22).

Poor sight distance to the flashers was noted at several locations. There were seven locations where sight distances were very limited, and a few locations had sight distances as low as 100 feet (30 meters). The use of the "SCHOOL AHEAD" signing and flashers suspended over the roadway helped to compensate for limited sight distances in some cases.

School officials and crossing guards at several locations indicated that some of the flashers had a history of flashing at inappropriate times. One set of flashers, for example, had flashed erratically for the past two years. In January of 1975, the clock stopped during a flashing phase and caused the lights to flash continually for several weeks. At another location, the flasher burned for over a year (according to local school officials). A number of school flashers had been purposely set to flash continually.

The operational reliability of flashers may help to increase driver compliance with the speed limit. Several flashers were programmed to operate long after all school buses and child activity had ended. Over 3 hours of daily operating time were noted at several locations. A shorter flashing period might have caused more drivers to respect the flasher.

Although several instances were noted where improvements to signs, flashers, and pavement markings were needed, a great majority of flasher locations had adequate traffic control devices. All 44 flashers in District 6 were working properly.

Figure 11. Post-Mounted Sign and Flashers.

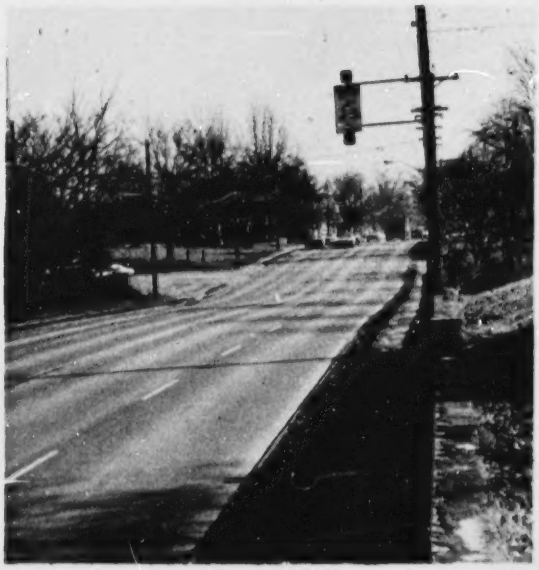


Figure 12. Sign and Flashers on Extension Arms.

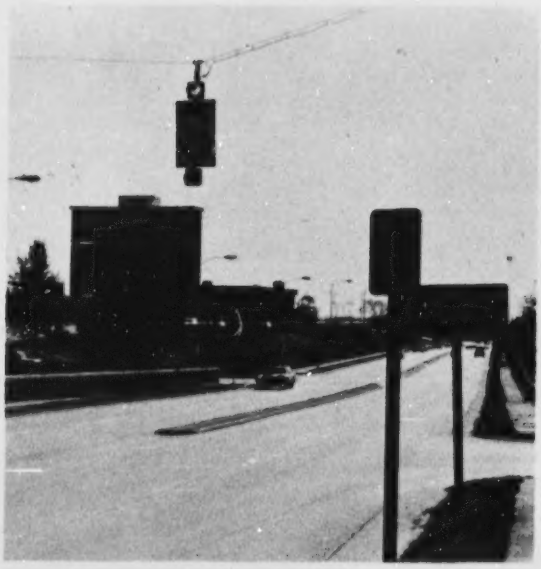


Figure 13. Suspended Sign and Flashers.

Figure 14. Sign and Flashers Obstructed by Trees (Viewed from 100 Feet (30 meters)).

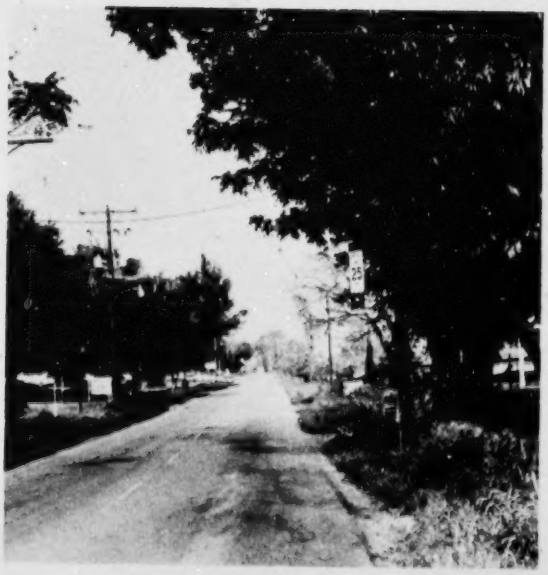


Figure 15. Sign and Flashers Twisted Away from Motorists' View.

Figure 16. Sign and Flashers Among Commercial Signs.

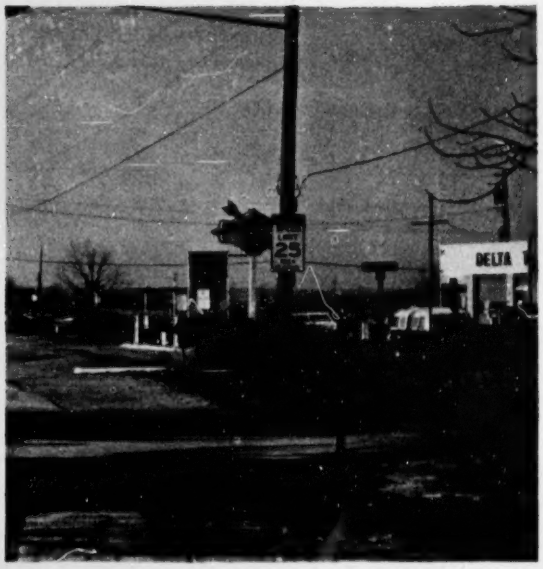


Figure 17. Sign and Flashers Located off the Road Shoulder.

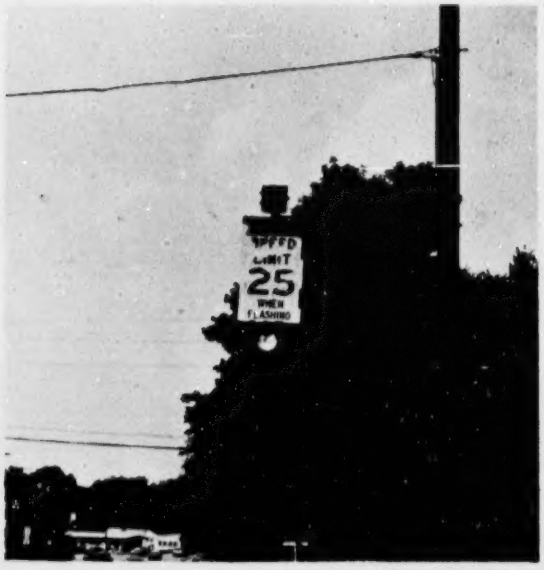


Figure 18. Paint Badly Chipped on Flasher Sign.

Figure 19. Worn Pavement Markings in School Zone.

Figure 20. Disconnected Flashers.

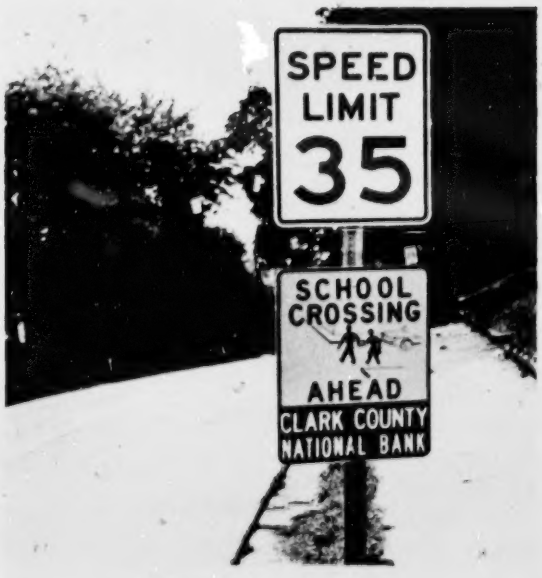


Figure 21. Commercial Message on School Sign Post.

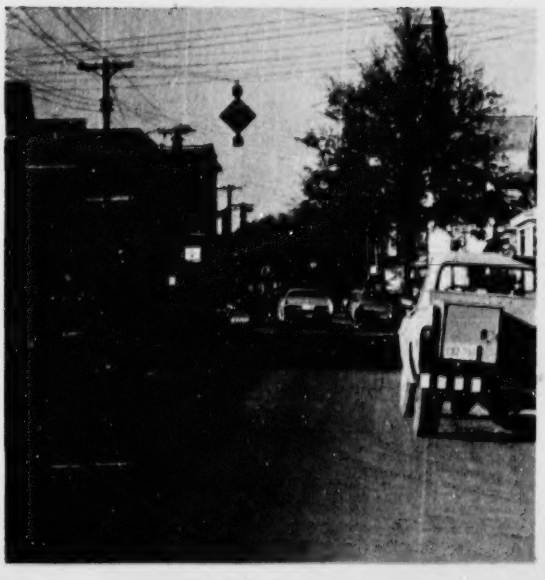


Figure 22. Portable Stop Sign.

RESULTS OF SPEED STUDIES

Speed measurements were made at 48 flasher locations. Five of the locations had crossing guards. Two speed studies were made at the same location involving the morning and the afternoon flashing periods to determine whether speeds were similar during the two periods.

Of the 48 speed locations, seven were in large urban areas (over 10,000 population), 13 in small urban areas (2,500-10,000 population), and 28 in rural areas or small towns (less than 2,500 population). Twenty-nine of the flasher locations in Districts 6, 7, and 9 were in low speed-limit zones (25 to 35 mph (11 to 16 m/s)); eleven were in medium speed-limit zones (36 to 45 mph (16 to 20 m/s)); and eight were in high speed-limit zones (46 to 55 mph (21 to 25 m/s)) (see Table 2). Thirty-nine sets of speed measurements were made on two-lane roads and nine were made on four-lane roads (Table 2).

Speeds were measured at 12 locations to determine whether there was any significant difference between the vehicle speeds before the flashers were actuated and after they were turned off. The difference in average speeds for these periods was less than 1 mph (0.5 m/s). Therefore, either period could be used for comparison with the flashing periods. For the 48 locations, the before flashing periods were usually used. Speeds monitored during the morning and afternoon flashing periods at one location were very similar. Either morning or afternoon speeds were taken at the 48 locations.

As mentioned earlier, there was a considerable increase in traffic volumes at several locations while the flashers were actuated. This resulted because the morning and afternoon flashing periods correspond closely with rush hours. To quantify the component of speed reduction due to the volume increase, a set of speed-volume curves was used. These curves were taken from the 1965 **Highway Capacity Manual** *(12)* and can be used to determine speed reductions expected as traffic volume increases on rural two- and four-lane roads (APPENDIX E). Because of interrupted flow of traffic in urban areas, speed-volume relationships for non-expressway, urban highways are not very well known. For each of the 16 rural speed-measurement locations, the traffic volumes (counted during speed studies) before and during flashing were found from appropriate curves in Figures E1 and E2. The corresponding speeds for these two volumes were then compared, and the reductions due to volume changes were tabulated (Table E1). The average reduction was only 0.8 mph (0.4 m/s) (16 locations); the maximum reduction was 2.5 mph (1.1 m/s) (two locations). Traffic volume was a major contributor to reduction at only two locations.

A statistical test was used to determine whether the speed reductions during flasher operation were significant. The sample sizes (n_1 and n_2) and standard deviations of each sample (σ_1, σ_2) were used to determine if the speed reductions ($\bar{x}_1 - \bar{x}_2$) were significant. Without considering the five locations where crossing guards were present, results showed that 84 percent of the flashers caused a significant speed reduction within 95 percent probability. Using a 99 percent probability, about 73 percent of the flashers caused a significant speed reduction. Details of the procedures and values from the statistical tests are given in APPENDIX F.

Although most of the flashers gave significant reductions in speeds, the magnitude of the reductions was not large in most instances. Out of 48 locations (excluding the five locations with crossing guards), 35 (71 percent) showed reductions of less than 4 mph (2 m/s) (Figure 23). The average reduction was 3.6 mph (1.6 m/s) per location. Plots of average speeds before and during flashing are given in Figure 24. The average speeds before and during flashing are shown in Table 3 for locations with various posted speed limits. Whereas the average speed dropped from 35 to 32 mph (16 to 14 m/s), the 85th-percentile speeds decreased only 5 mph (2 m/s). Locations with the highest speed limit had the lowest reduction in 85th-percentile speeds. Average speeds reduced more at locations with the highest speed limits. The 85th-percentile speed in several rural areas during flashing times was 54 mph (24 m/s).

TABLE 2. TYPES OF SPEED STUDY LOCATIONS

NORMAL SPEED LIMIT	NUMBER OF LOCATIONS						
	LARGE URBAN AREAS (OVER 10,000 POPULATION)		SMALL URBAN AREAS (2,500 to 10,000 POPULATION)		RURAL AREAS (LESS THAN 2,500 POPULATION)		TOTALS
	TWO-LANE	FOUR-LANE	TWO-LANE	FOUR-LANE	TWO-LANE	FOUR-LANE	
25 to 35 mph (11 to 16 m/s)	4	1	7	3	14	0	29
36 to 45 mph (16 to 20 m/s)	1	1	2	0	5	2	11
46 to 55 mph (21 to 25 m/s)	0	0	1	0	5	2	8
Totals	5	2	10	3	24	4	48

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Figure 23. Speed Reduction Due to Flasher Operation.

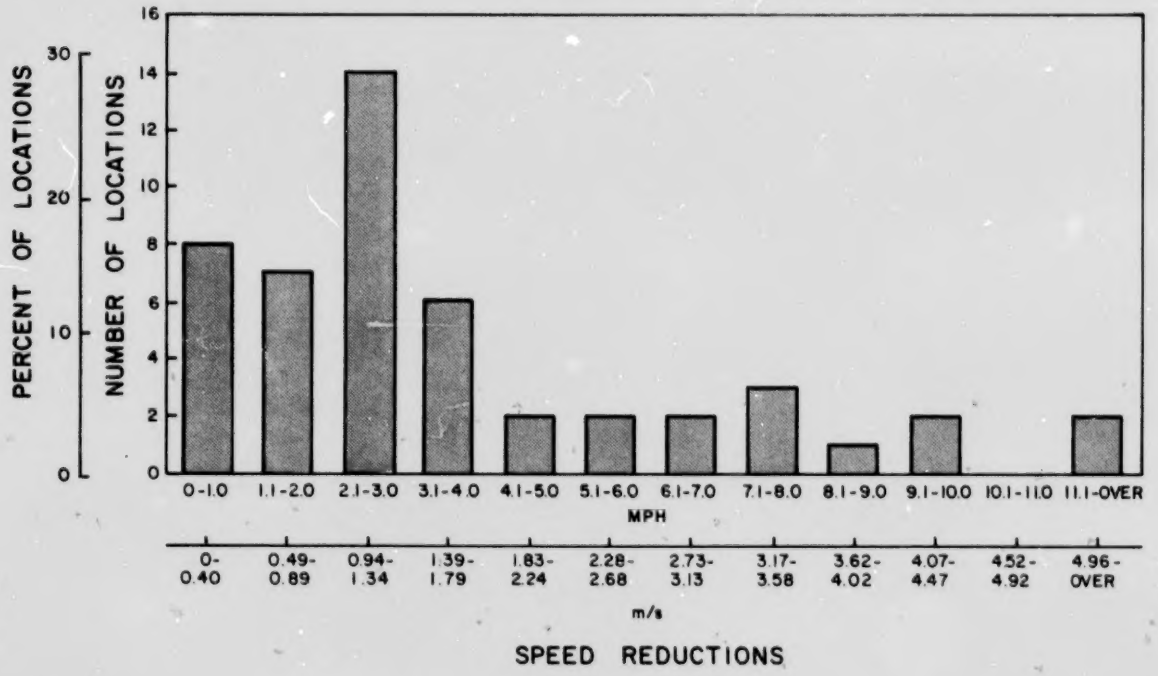

Figure 24. Average Vehicle Speeds Before and During Flashing.

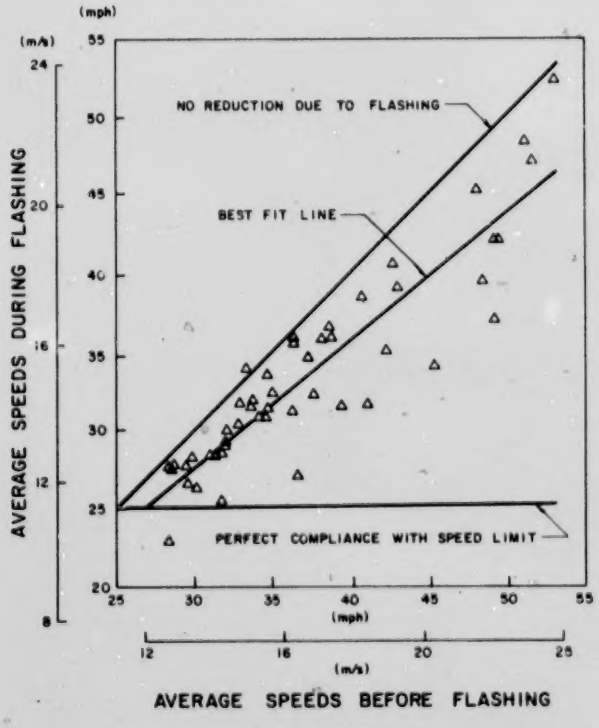

TABLE 3. SPEEDS DURING FLASHING AND NON-FLASHING FOR ROADS WITH VARIOUS SPEED LIMITS

SPEED LIMIT		AVERAGE SPEED				85th PERCENTILE SPEED			
		BEFORE FLASHING		DURING FLASHING		BEFORE FLASHING		DURING FLASHING	
(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)
35	16	33	15	31	14	40	18	36	16
45	20	36	16	33	15	44	20	40	18
55	25	50	22	45	20	56	25	54	24
Other		38	17	34	15	46	21	40	18
Total		35	16	32	14	44	20	39	17

Cummulative-type speed distribution curves are shown in Figure 25. Motorist compliance with the 25-mph (11-m/s) speed limit was only 18 percent during the flashing periods; however, eight percent of the vehicles traveled below that speed with the flashers off. The flashers, therefore, were successful in gaining compliance from only ten percent of the motorists. The 85th-percentile speed while flashing was 39 mph (17 m/s) -- 19 mph (8 m/s) over the speed limit.

The 10-mph (4.5-m/s) paces before and during flashing periods are shown in Figure 26. The pace is the increment of speed including the greatest number of vehicles. The higher the percentage of vehicles in the pace, the more uniform the vehicle speeds, and, therefore, the safer the traffic flow *(14)*. The pace ranged between 29.1 and 39.1 mph (13.0 and 17.5 m/s) before flashing and between 24.3 and 34.3 mph (10.9 and 15.3 m/s) during the flashing periods. The percentage of vehicles in the 10-mph (4.5 m/s) pace was 51.2 before flashing and 52.0 while flashing. For 35-mph (16-m/s), 45-mph (20-m/s), and "other" speed limits, there was virtually no difference in the uniformity of speeds before and during flashing periods. However, at 55-mph (25-m/s) locations, the percent of vehicles in the pace was 58.0 before flashing and only 43.3 while flashing. This drop of nearly 15 percent indicated less speed uniformity and, therefore, a greater risk of collision between vehicles.

Speeds at five locations where crossing guards directed pedestrian and vehicles during the flashing periods were compared to speeds controlled by flashers only. Where flashers were not actuated and no crossing guards present, the speeds averaged 32.6 mph (14.6 m/s). With the flashers alone, the speed was 29.9 mph (13.4 m/s), a 2.7-mph (1.2-m/s) reduction. With the flasher on and crossing guards presents, the average speed was 23.7 mph (10.6 m/s), an 8.9-mph (4.0-m/s) reduction (Table 4).

VARIABLES IN FLASHER EFFECTIVENESS

Speed reductions attributable to the flashers ranged from 0 to 12 mph (0 to 5 m/s). Inasmuch as only a few of the locations had the desired effectiveness, some physical features which might affect motorist compliance were tested for significance. Some of these factors were average speeds, pedestrian volumes, number of school buses, pavement width, sight distance, enforcement, proximity to intersections, and flasher reliability.

Average Speeds

Greater reductions in speeds were found at locations where normal speeds were higher (Figure 27). The wide scatter of data points is due to other variables. The cumulative percentages of locations in three separate speed ranges are plotted against speed reductions in Figure 28. The speed ranges represent the average speed of vehicles before the flashers were actuated. As can be seen, the higher the speed range, the greater the speed reduction. The average reductions in each of the three speed ranges are given in Table 5. The reductions were 2.4, 3.9, and 6.2 mph (1.1, 1.7, and 2.8 m/s) for the lowest, middle, and highest speeds, respectively. However, the speeds in the 46- to 55-mph (20- to 25-m/s) range exceeded the speed limit by 18.1 mph (8.1 m/s); speeds in the 35- to 45-mph (16- to 20-m/s) and the 25- to 35-mph (11- to 16-m/s) ranges exceeded the limit by 9.7 and 4.2 mph (4.3 and 1.9 m/s), respectively. Whereas the flashers at the high-speed locations caused slightly greater reductions, the average speeds exceeded the 25-mph (11-m/s) limit by a greater amount than at low-speed locations.

Figure 25. Cumulative Speed-Distribution Curves.

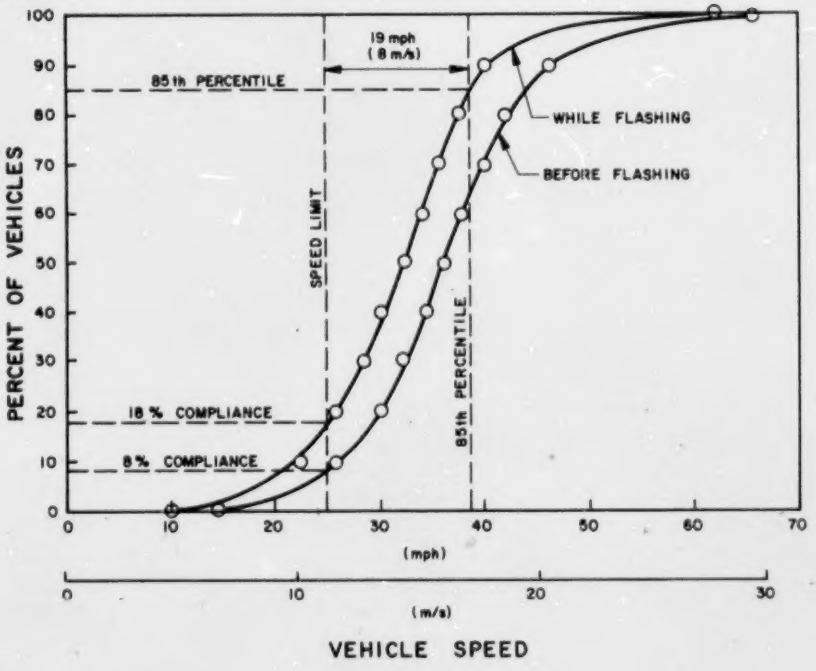

Figure 26. Speed-Distribution Curves.

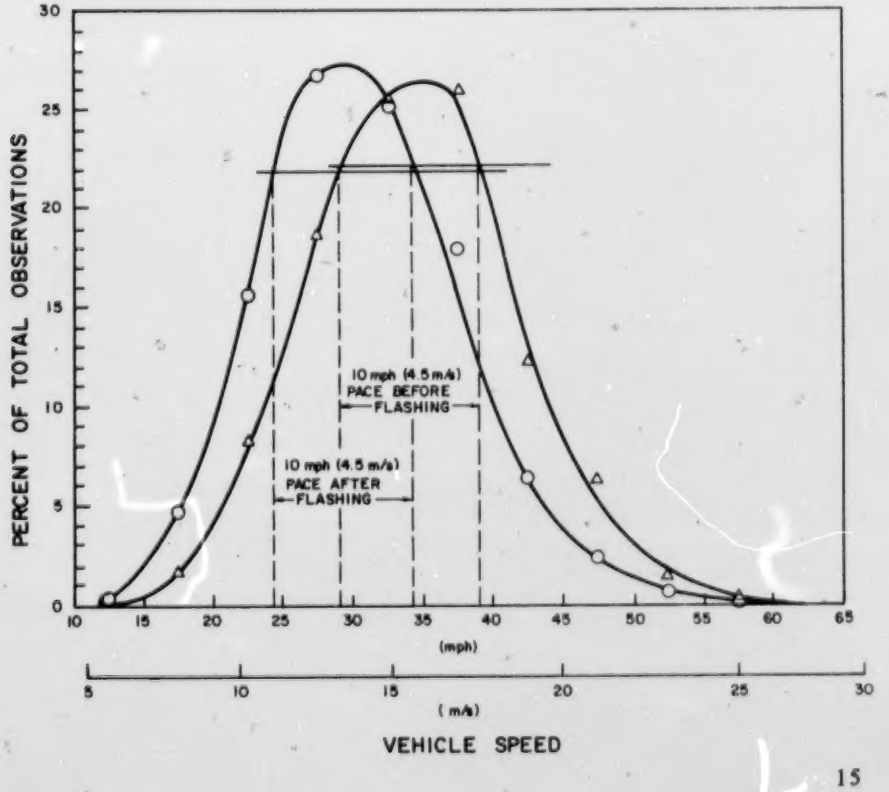

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TABLE 4. SPEED REDUCTIONS AT SCHOOL FLASHER LOCATIONS WITH AND WITHOUT CROSSING GUARDS

LOCATION NUMBER	AVERAGE VEHICLE SPEED						SPEED REDUCTION			
	BEFORE FLASHING		DURING FLASHING		FLASHING AND GUARD		FLASHER ONLY		FLASHER AND GUARD	
	(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)
81	31.5	14.1	28.6	12.8	19.4	8.7	2.9	1.3	12.1	5.4
101	34.5	15.4	31.4	14.0	24.5	11.0	3.1	1.4	10.0	4.5
68	30.9	13.8	28.5	12.7	22.8	10.2	2.4	1.1	8.1	3.6
120	34.2	15.3	30.8	13.8	23.1	10.3	3.4	1.5	11.1	5.0
50	32.0	14.3	30.1	13.4	28.7	12.8	1.9	0.8	3.3	1.5
Totals	32.6	14.6	29.9	13.4	23.7	10.6	2.7	1.2	8.9	4.0

Figure 27. Relationship between Average Normal Speed and Speed Reductions during Flashing Periods.

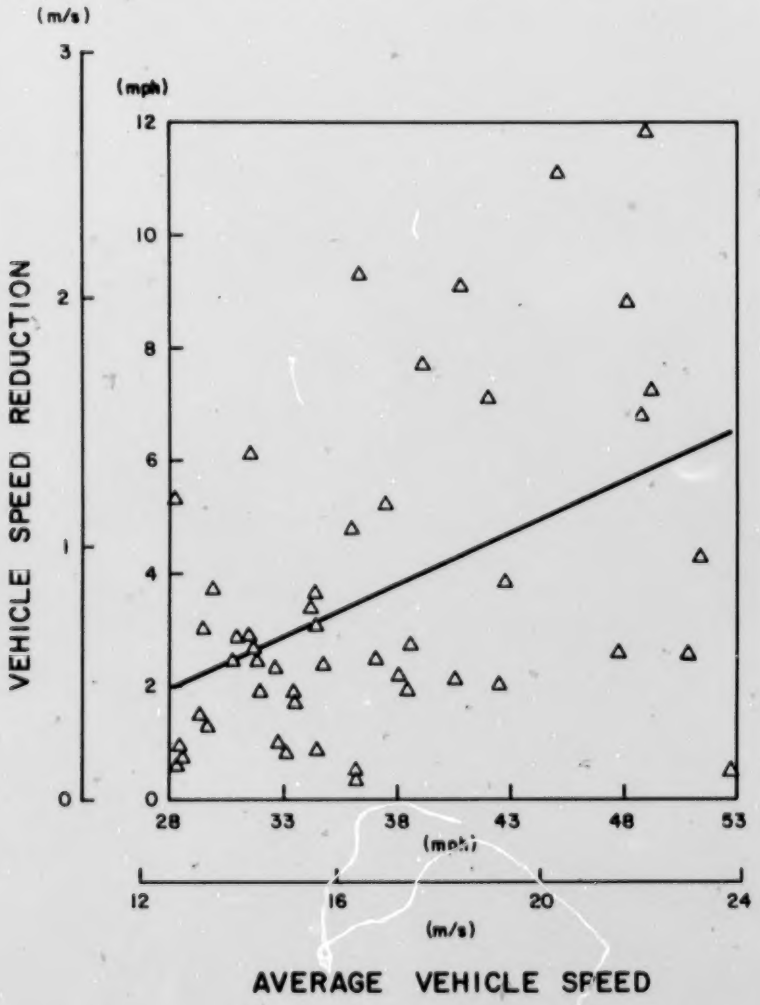

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Figure 28. Speed Reductions by Speed Groups.

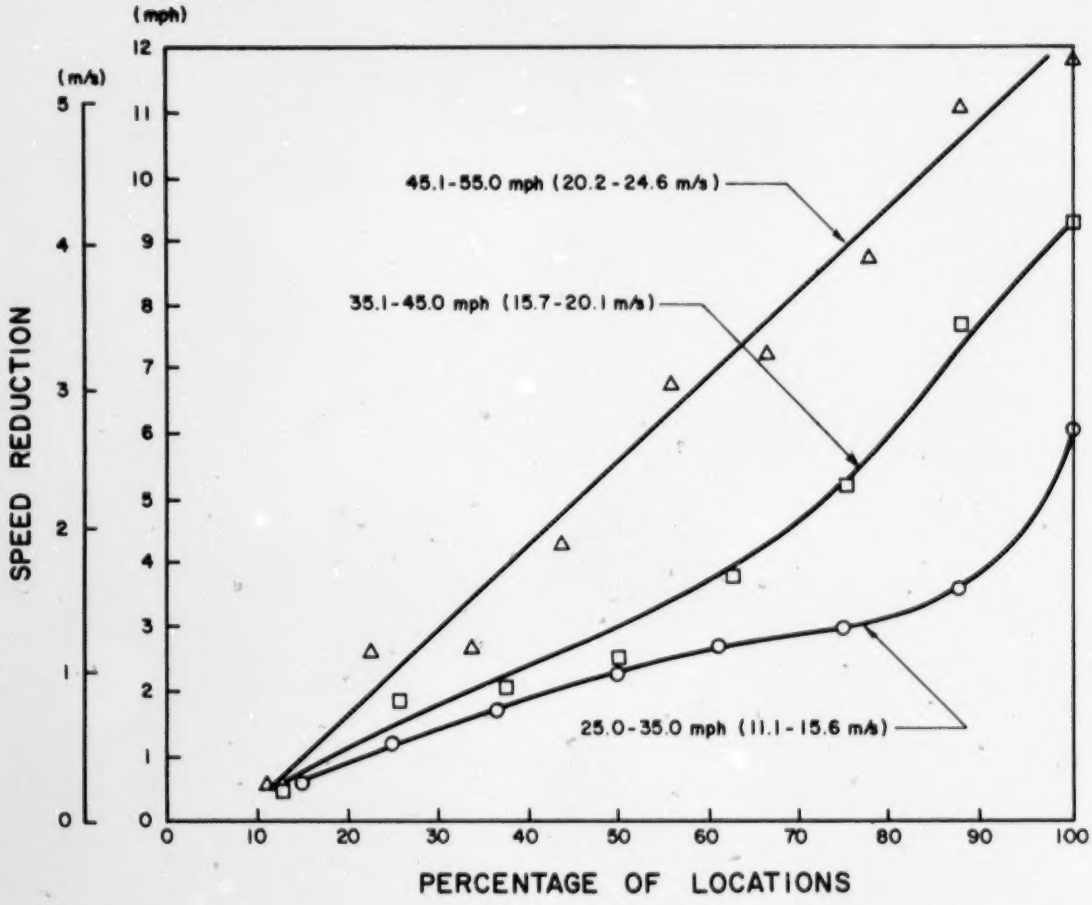


TABLE 5. VEHICLE SPEED REDUCTIONS AND VIOLATIONS FOR VARIOUS SPEED RANGES

AVERAGE VEHICLE SPEEDS		NUMBER OF LOCATIONS	AVERAGE SPEED REDUCTION		AVERAGE VEHICLE SPEED ABOVE 25 MPH LIMIT DURING FLASHING	
(mph)	(m/s)		(mph)	(m/s)	(mph)	(m/s)
25 to 35	11 to 16	24	2.4	1.1	4.2	1.9
36 to 45	16 to 20	16	3.9	1.7	9.7	4.3
46 to 55	21 to 25	9	6.2	2.8	18.1	8.1
Totals		49	3.6	1.6	8.5	3.8

Pedestrian Volumes

The relationship between pedestrian volumes at school flasher locations and speed reductions was not discernable from plots of the two variables. The least-squares fit for low-speed areas (25 to 35 mph (11 to 16 m/s)), shown in Figure 29, indicates that speed reductions increased as pedestrian volumes increased. However, the speeds reduced only about 2 mph (1 m/s) as the pedestrian volume increased from 50 to 400 per day.

While recording speeds at four locations, the data were coded to indicate whether children were or were not visible in the school zone. Speeds reduced about 2 mph (1 m/s) when children were visible to the motorist.

Volumes of School Buses

In many school zones, pedestrian volumes were very low because most children, particularly in rural areas, were bused to and from school. The number of school buses entering and leaving a school was considered to be a possible influence on vehicle speeds. A plot of speed reductions and volumes of school buses gave a very large scatter of data points at locations where there was a small number of buses. Figure 30 shows a least-squares line for low-speed locations (25 to 35 mph (11 to 16 m/s)). The reduction in speed was only about 2 mph (1 m/s) as the number of buses per day increased from 0 to 32.

Figure 29. Influence of Pedestrian Volumes on Vehicle Speed Reduction.

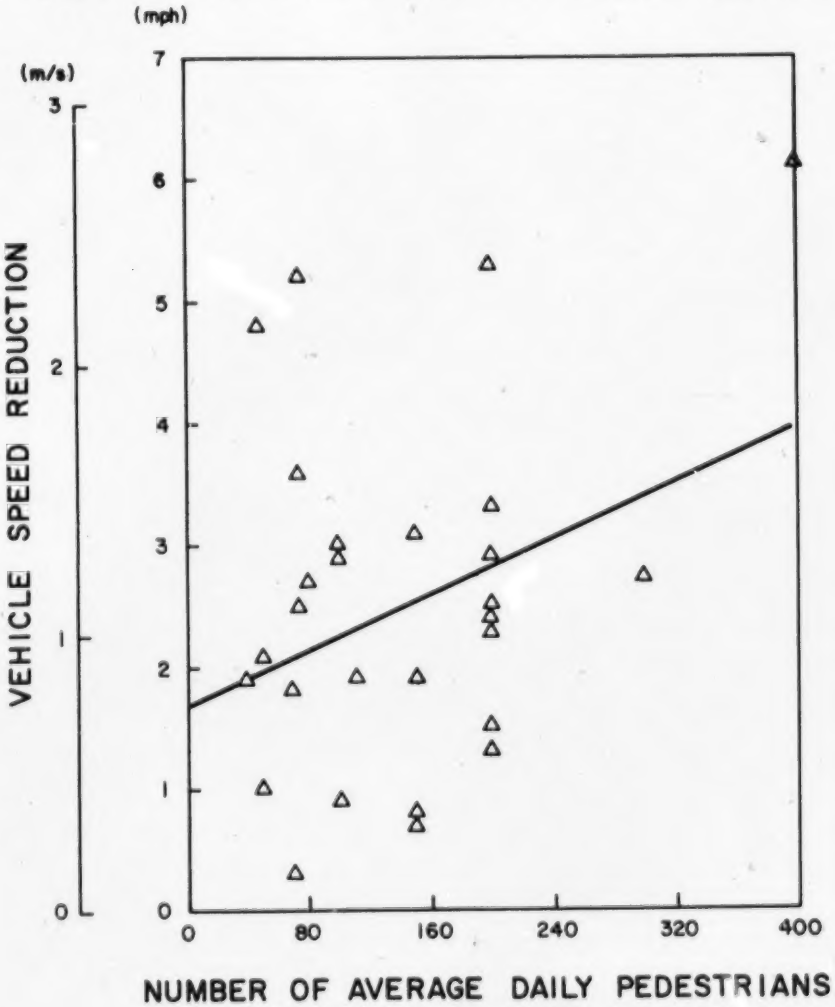
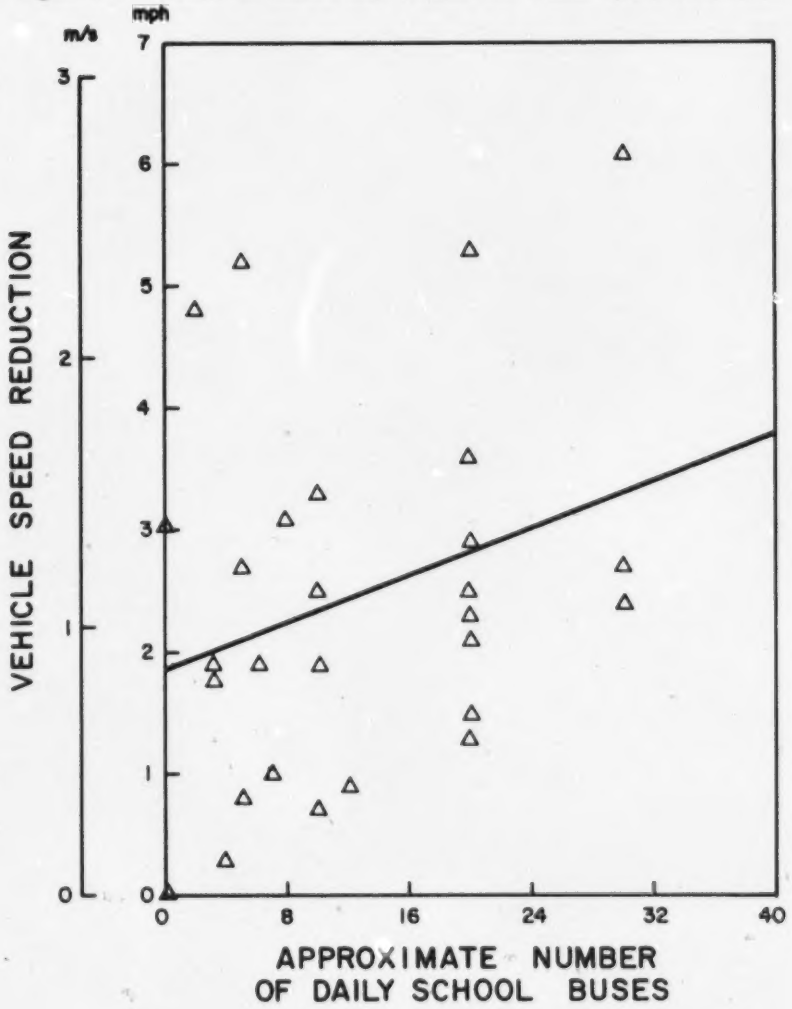


Figure 30. Effect of School Bus Volume on Vehicle Speed Reduction.



Highway Width

Of the 48 sites, 40 were on two-lane roads. The average reduction in speed on four-lane roads was 3.5 mph (1.6 m/s); this compared to 3.6 mph (1.6 m/s) on two-lane roads.

Sight Distance

Because most of the locations studied were in low-speed areas (25 to 35 mph (11 to 16 m/s)), sight distances were usually not critical. Flashers in high-speed areas were suspended above the roadway for better visibility. There were a few flashers, however, which had sight distances less than 200 feet (61 meters) in one or both directions.

A summary of the speed reductions at the five locations having the least sight distances is given in Table 6. Average speeds before flashing ranged from 30 to 39 mph (13 to 17 m/s). Sight distances ranged from 100 to 400 feet (30 to 122 meters). Speed reductions at these locations varied from -0.8 to +1.9 mph (-0.4 to +0.8 m/s) and averaged only 0.8 mph (0.4 m/s).

Speed Enforcement

At seven locations, local or state police regularly parked in the school zones and cited motorists violating the 25-mph (11-m/s) limit. The average speed before flashing was about 42 mph (19 m/s), and the average speed reduction while flashing was 8.4 mph (3.8 m/s) (Table 7). This reduction was considerably more than the 3.9-mph (1.7-m/s) average reduction at locations in the 35- to 45-mph (16- to 20-m/s) range (given in Table 5). The average speeds during flashing periods at these locations still exceeded the 25-mph (11-m/s) speed limit.

TABLE 6. EFFECT OF POOR SIGHT DISTANCE ON SPEED REDUCTION

LOCATION NUMBER	SIGHT DISTANCE TO FLASHER				AVERAGE VEHICLE SPEED (NON-FLASHING)		SPEED REDUCTION WHILE FLASHING	
	DIRECTION A		DIRECTION B					
	(feet)	(meters)	(feet)	(meters)	(mph)	(m/s)	(mph)	(m/s)
82	100	30	150	46	36	16	0.5	0.2
6	100	30	250	76	33	15	-0.8	-0.4
119	200	61	400	121	33	15	1.0	0.4
65	250	76	400	121	30	13	1.4	0.6
103	200	61	400	121	39	17	1.9	0.8
Average	170	52	320	97	34	15	0.8	0.4

TABLE 7. THE EFFECT OF POLICE ENFORCEMENT OF SPEED LIMIT IN SCHOOL ZONES

LOCATION NUMBER	AVERAGE VEHICLE SPEEDS (NON-FLASHING)		SPEED REDUCTION WHILE FLASHING	
	(mph)	(m/s)	(mph)	(m/s)
2	42	19	7.1	3.2
3	49	22	6.8	3.0
13	36	16	9.3	4.2
32	49	22	11.8	5.3
31	39	17	7.7	3.4
37	36	16	4.8	2.1
12	45	20	11.1	5.0
Average	42	19	8.4	3.8

Speed Zones Near Signalized Intersections

Five locations with traffic signals or stop signs within the school zone were studied. Speed reductions were less than 1 mph (0.4 m/s) at four locations and 3.6 mph (1.6 m/s) at the remaining location. All locations had non-flashing, average speeds below 35 mph (16 m/s). The low speed was probably judged reasonable by motorists; and, therefore, no further reductions in speed were deemed necessary.

Flasher Reliability

Past reliability of a school flasher may be an important factor in the compliance and obedience of local motorists to speed limits in school zones. Flasher reliability, here, refers to the operational validity of the flasher. Sometimes flashers were actuated at incorrect times, did not operate for several days, or flashed continually. Speed studies at three such locations with a history of incorrect flashing periods showed an average speed reduction of only 1.7 mph (0.8 m/s).

To determine the effect of long flashing times on speed reductions, the average period of operation was computed for each location. There were ten locations which had average periods from 70 to 105 minutes. None of these locations had speed reductions over 2.6 mph (1.2 m/s) while flashing. Twenty of the remaining 39 locations (about 51 percent) had speed reductions over 2.6 mph (1.2 m/s) and an average flashing period of 60 minutes or less. These findings do not indicate that short flashing periods will necessarily result in large speed reductions. They do suggest that excessive flashing periods may cause disrespect for the flashers.

Other Factors

If the school zone has good physical characteristics and the flashers are properly maintained and operated, the flasher may contribute to significant speed reductions. Crossing guards and police enforcement further assure speed reductions. However, certain other conditions may completely negate the effectiveness of the flasher.

An important observation was that several school flashers were in operation at locations which had low pedestrian volumes and low vehicle speeds and volumes. While the flashers may have helped, the installation of school warning signs and pavement markings would have likely been equally effective. Since the vehicles were already traveling near 25 mph (11 m/s), there was no further inducement to reduce speeds. While most school flashers are probably warranted, a few locations do not need them and may eventually cause motorists to ignore them.

Speeds were not monitored at any of the locations where the flashers operated continually because non-flashing speed data could not be obtained. Since these flashers operate on weekends and at night, the local motorists probably ignore them anyhow.

SUMMARY AND CONCLUSIONS

The following findings and conclusions were based on studies of school flashers in Districts 6, 7, and 9 during 1974 and 1975:

1. Speed reductions attributable to flashers were statistically significant at the 95.0-percent level at 84 percent of the locations. The average speed reduction was 3.6 mph (1.6 m/s), while 71 percent of the locations showed speed reductions less than 4 mph (1.8 m/s). Only two locations yielded speed reductions over 10 mph (4.5 m/s).

2. The 85th-percentile speeds decreased by about 5 mph (2.2 m/s) for all locations. The higher-speed locations had lower reductions (2 mph (0.9 m/s)) than the low-speed locations (4 mph (1.8 m/s)).

3. The 85th-percentile speeds at all locations during flashing periods exceeded the 25-mph (11-m/s) limit by about 19 mph (8.3 m/s).

4. Motorist compliance with the 25-mph (11-m/s) speed limit was only about 18 percent; eight percent of the vehicles traveled below that speed when flashers were not operating.

5. Uniformity of driving speeds (10-mph (4.5-m/s) pace) was the same at low-speed (25 to 35 mph (11 to 16 m/s)) and medium-speed (36 to 45 mph (16 to 20 m/s)) locations whether the flashers were on or not. However, at high-speed locations (46 to 55 mph (21 to 25 m/s)), a 15-percent drop of vehicles in the 10-mph (4.5-m/s) pace was noted -- indicating that the inter-vehicle accident potential is increased when the flashers are on.

6. Crossing guards contributed to a drop of vehicle speeds of about 9 mph (4 m/s) and the average speeds were under 25 mph (11 m/s) at four of the five locations. Without the crossing guards at these same locations, the speed reduction averaged only 2.7 mph (1.2 m/s). Crossing guards were stationed at about ten percent of all locations.

7. Regular speed enforcement in school zones by police agencies caused average speed reductions of 8.4 mph (3.8 m/s) at seven locations.

8. Speed reductions at high-speed locations were slightly higher than at other locations. However, the average speeds exceeded the 25-mph (11-m/s) limit by about 18 mph (8 m/s) at high-speed locations compared to 9.7 mph (4.3 m/s) and 4.2 mph (1.9 m/s) at medium- and low-speed locations, respectively.

9. Pedestrian volumes in the school zones contributed to a slight decrease in vehicle speeds (about 2 mph (1 m/s)). Also, school bus volumes contributed to a slight decrease in vehicle speeds (about 2 mph (1 m/s)).

10. Highway width did not appear to affect speed reductions.

11. Short sight distances between motorists and school flashers contributed to the ineffectiveness of flashers at five locations.

12. Average decreases in speed of less than 1 mph (0.4 m/s) during flashing periods were attributed to volume increases at only two locations.

13. Signalized or "stop sign" intersections adjacent to or between school flashers resulted in virtually no speed reductions in four of five such locations.

14. Excessively long flashing periods at ten locations resulted in speed reductions of less than 2.6 mph (1.2 m/s).

15. School flashers at three locations, with a recent history of inappropriate flashing, yielded an average speed reduction of only 1.7 mph (0.8 m/s).

16. Several flasher installations were not warranted because of low pedestrian volumes and low vehicle speeds and volumes. A few continually flashing lights were also found.

17. Nearly all school flasher locations have favorable as well as unfavorable features which contribute to driver compliance or non-compliance with the 25-mph (11-m/s) limit. A single, significant defect can render the flasher ineffective.

18. About 14 percent of the school flashers were defective or malfunctioned. Major malfunctions included inoperative clocks and defective bulbs or fuses. Other deficiencies included flashers mounted among commercial signing, obstructed view, deteriorating signs, worn pavement markings, non-uniform signs, and erratic flashing periods.

RECOMMENDATIONS

The following recommendations are based on the findings and conclusions noted previously:

1. A high priority should be given to regular inspection and maintenance of school flashers. Trimming tree branches which hide the flashers, replacing post-mounted flashers with overhead flashers in commercial areas or where sight distance is restricted, and replacing non-uniform signs are also recommended.

2. School officials should be urged to notify District Offices whenever flashers malfunction.

3. All flashers should be equipped and set to actuate at times corresponding to pedestrian activity. Manual override switches should be provided for irregular occasions of activity.

4. Warrants for school flashers should be revised to provide more detail.

5. All school flashers which are not needed (based on considerations of pedestrian volumes, vehicle volumes, vehicle speeds, and sight distances) should be removed and replaced by warning signs (pavement markings may accompany the signs).

6. Installation of each new flasher should be governed strictly on the warrants only after a careful field investigation of the location.

7. Speed enforcement should be encouraged.

8. Uniformed guards are recommended at crossings where short vehicle gaps and high speeds prevail.

9. Speed limits in school zones should be raised to 35 mph (16 m/s) wherever the approaching roadway has a posted speed of 55 mph (25 m/s). This recommendation has been supported by others *(15)* for locations where speed variations are increased during flashing periods.

10. In school zones near major intersections, pedestrian hazards may exist when turning movements are heavy. Special pedestrian phasing may be used with the traffic signal to assure adequate gaps for street crossings. The use of crossing guards may also be desirable at such locations.

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APPENDIX A

CRITERIA FOR SCHOOL FLASHERS
(March 12, 1973)

1. It is not desirable to install school flashers where the 85th-percentile speed of motorists is 50 mph (22 m/s) or greater. Few motorists will abruptly change their speeds from 50 to 25 mph (22 to 11 m/s) simply because they see a sign telling them to do so. Indeed, any abrupt change in speed of a car traveling in a queue of relatively fast moving traffic is extremely dangerous and has the potential of causing rear-end type collisions.

2. The school should be adjacent to the highway in order for a school flasher to be effective. It is confusing for a driver to see a school flasher in operation and not to see a school or any pupils.

3. The 25 MPH WHEN FLASHING school sign should not be installed at any location where the speed limit is 25 mph (11 m/s) or less, because the sign indicates to motorists that the speed limit is other than (greater) 25 mph (11 m/s) when the sign is not flashing. If it is determined that flashers are needed in a 25 mph (11 m/s) speed zone, standard school signs should be used.

4. Flashers should be installed at locations where there are a significant number of school children crossing the highway or walking along the shoulder of the road and where a reasonable reduction in motorists' speeds would enhance the safety of children.

School flashers should not flash when there are no pupils visible to motorists, as this practice encourages drivers to ignore the signs.

5. In general, it is best for school buses entering or leaving school grounds to follow the same rules of the road as other traffic. In exceptional circumstances, school flashers may be installed for school buses. An example is: on a two-lane highway where sight distance is extremely limited and because of restricted geometrics, school buses are required to travel in the opposing lane of traffic to execute a turn from the highway to the school, or vice versa.

School flashers may impart a false sense of security to school children. The safest school crossing is one patrolled by an adult guard (more to control the children than traffic). No traffic control device can substitute for alertness and awareness by the school children.

APPENDIX B

72-05.1000 SCHOOL FLASHER ASSEMBLIES

When warranted by an engineering study, school flasher assemblies may be installed at schools located adjacent to state-maintained facilities. The assembly shall consist of a sign (24" x 48") with the message SCHOOL/SPEED/LIMIT/25/ WHEN FLASHING. The message SCHOOL shall be black on a yellow background (24" x 8") and the remainder of the sign shall be black on white (see Section 7B-12 of the Uniform Traffic Control Devices Manual). The school flasher assembly shall also consist of 8" flashing beacons utilizing yellow indications with one indication mounted over the sign and one indication mounted under the sign. These assemblies shall normally be installed 1/8 mile in advance of the school on all approaches when practical.

At the end of the 25-mph speed zone, a speed limit sign for the following section of highway shall be posted. This sign shall be located opposite the school flasher assembly for opposing traffic on two-way streets, and when practical 1/8 mile beyond the school on one-way streets.

Due to the restrictive speed limit, caution should be exercised when recommending flashers to be installed on high speed facilities. School flasher operation should be for as short a period of time as practical. Normally periods of operations will occur during school convening and dismissal hours. Additional periods of operation may be warranted, such as lunch time, where a large number of walkers are present. Suggested timing will be submitted for approval by the district engineer along with any request for school flashers.

In addition to the above, the same requirements for approval, installation, etc. shall apply to school flasher assemblies as that which applies to other signals.

APPENDIX C

NUMBER OF SCHOOL FLASHERS BY COUNTY AND DISTRICT

DISTRICT NO. 1		DISTRICT NO. 2		DISTRICT NO. 3		DISTRICT NO. 4	
Ballard	2	Caldwell	2	Allen	3	Breckinridge	2
Calloway	3	Christian	2	Barren	6	Grayson	3
Carlisle	1	Daviess	9	Butler	2	Green	1
Crittenden	0	Hancock	1	Edmonson	2	Hardin	12
Fulton	2	Henderson	6	Logan	6	Hart	0
Graves	4	Hopkins	9	Metcalfe	1	Larue	1
Hickman	2	McLean	4	Monroe	1	Marion	3
Livingston	3	Muhlenberg	8	Simpson	2	Meade	3
Lyon	0	Ohio	3	Todd	3	Nelson	3
McCracken	8	Union	2	Warren	2	Taylor	1
Marshall	2	Webster	2	Total	28	Washington	2
Trigg	1	Total	48			Total	31
Total	28						

DISTRICT NO. 5		DISTRICT NO. 6		DISTRICT NO. 7		DISTRICT NO. 8	
Bullitt	4	Boone	5	Anderson	2	Adair	1
Franklin	2	Bracken	2	Bourbon	5	Casey	2
Henry	2	Campbell	10	Boyle	2	Clinton	1
Jefferson	41	Carroll	3	Clark	5	Cumberland	2
Oldham	4	Gallatin	2	Fayette	6	Lincoln	3
Shelby	3	Grant	3	Garrard	1	McCreary	2
Spencer	0	Harrison	2	Jessamine	3	Pulaski	9
Trimble	0	Kenton	13	Madison	7	Rockcastle	3
Total	56	Owen	1	Mercer	4	Russell	2
		Pendleton	2	Montgomery	0	Wayne	4
		Robertson	1	Scott	1	Total	29
		Total	44	Woodford	5		
				Total	41		

DISTRICT NO. 9		DISTRICT NO. 10		DISTRICT NO. 11		DISTRICT NO. 12	
Bath	2	Breathitt	3	Bell	3	Floyd	8
Boyd	10	Estill	2	Clay	2	Johnson	4
Carter	2	Lee	0	Harlan	6	Knott	4
Elliott	1	Magoffin	2	Jackson	2	Lawrence	1
Fleming	3	Menifee	1	Knox	1	Letcher	5
Greenup	10	Morgan	2	Laurel	6	Martin	5
Lewis	2	Owsley	1	Leslie	1	Pike	14
Mason	3	Perry	5	Whitley	3	Total	41
Nicholas	1	Powell	2	Total	24		
Rowan	1	Wolfe	1				
Total	35	Total	19				

Total School Flashers on State Maintained Roads = 424

APPENDIX D

LISTING OF INSPECTED SCHOOL FLASHERS

REFERENCE NUMBER	DISTRICT	COUNTY	ROUTE	LOCATION	SCHOOL	EXISTING SPEED LIMIT (mph)	EXISTING SPEED LIMIT (m/s)	SCHOOL ZONE OR CROSSING	ESTIMATED PEDESTRIAN ADT	ESTIMATED BUS ADT
1	6	Boone	KY 237	Hebron	Conner Jr. and Sr. H.S.	45	20	Zone	50	35
2*	6	Boone	US 42-127	Florence	Ockerman Elem. & Jr. H.S.	45/55	20/25	Zone	300	40
3*	6	Boone	US 42-127	10 mi W of Union	New Haven Elem.	55/50	25/22	Zone	25	10
4*	6	Boone	US 25	Florence	St. Paul Elem.	35	16	Crossing	75	20
5*	6	Boone	KY 18	Florence	Florence Elem.	35	16	Zone	100	12
6*	6	Bracken	KY 10	Germantown	Germantown Elem.	35	16	Zone	150	5
7	6	Bracken	KY 19	Brooksville	Bracken Co. H.S.	25	11	Zone	50	8
8*	6	Campbell	KY 8	California	A. J. Jolly Elem.	55/50	25/22	Zone	0	10
9	6	Campbell	KY 1120-US 27	Ft. Thomas	Woodfill Elem.	25/35	11/16	Zone	300	0
10	6	Campbell	KY 9	Wilder	St. John's Elem.	45	20	Zone	10	5
11	6	Campbell	11th St.	Newport	A. D. Owens School			Zone		
12*	6	Campbell	US 27	Coldspring	St. Joseph Elem.	40	18	Zone	50	10
13*	6	Campbell	KY 8	Melbourne	St. Philip Elem.	40	18	Zone	15	5
14	6	Campbell	KY 547	Silver Grove	Silver Grove Elem. & H.S.	25	11	Zone	150	2
15	6	Campbell	KY 1120	Ft. Thomas	Highlands H.S.	25	11	Zone	400	0
16	6	Campbell	KY 1120	Ft. Thomas	St. Thomas Elem. & H.S.	25	11	Zone	200	0
17	6	Campbell	Taylor Ave.	Bellevue	Sacred Heart Elem.	25	11	Zone	150	0
18*	6	Carroll	US 127	Carrollton	Carroll Co. H.S. & Vocational School	45	20	Zone	0	20
19	6	Carroll	US 42-127	Ghent	Ghent Elem.	35	16	Zone	25	8
20	6	Carroll	US 42 NCL	Carrollton	Hwy. 42 Elem.	45	20	Zone	0	
21	6	Gallatin	US 42-127	Warsaw	Gallatin Co. H.S.	35	16	Zone	100	10
22	6	Gallatin	US 127	Glencoe	Glencoe Elem.	35	16	Zone	25	5
23	6	Grant	US 25	Crittenden	Crittenden Elem.	35	16	Zone	50	5
24	6	Grant	US 25	Williamstown	Williamstown Elem.	35	16	Zone	200	0
25*	6	Grant	US 25	Mason	Mason Elem.	35	16	Zone	25	
26	6	Harrison	KY 536	1.0 mi W of Cynthiana	Westside Elem.	55/50	25/22	Zone	0	10
27	6	Harrison	KY 982 & Webster Ave.	Cynthiana	Harrison Co. H.S. & Vocational School	25	11	Crossing	Continuous	0
28	6	Kenton	KY 1303	2.5 mi W of Independence	Beechgrove Elem.	35	16	Zone	75	12
29*	6	Kenton	KY 371 - Buttermilk Pike	Crescent Springs	Crescent Springs Elem.	35	16	Zone	75	10
30	6	Kenton	KY 17	Independence	Kenton Elem. & H.S.					39
31*	6	Kenton	KY 16 & Sipple	Taylor Mill	Taylor Mill Elem.	45	20	Zone	75	12
32*	6	Kenton	KY 16	2.0 mi E of Nicholson	Twenhofel Jr. H.S.	55/50	25/22	Zone	50	20
33	6	Kenton	KY 17 & 26th	Covington	Covington Holmes H.S.	30	13	Zone	500	5
34	6	Kenton	KY 17 & Iowa	Covington	9th District Elem.	35	16	Zone	250	0
35	6	Kenton	KY 236	Erlanger	Arnett Elem.	35	16	Zone	75	0
36	6	Kenton	KY 236	Erlanger	Lloyd H.S. Tichenor M.S.	35	16	Crossing	200	0
37*	6	Kenton	KY 1072	Ft. Wright	St. Agnes Elem.	35	16	Zone	50	2
38	6	Kenton	US 25-42-127	Elsmere	St. Henry H.S. & Elem.	35	16	Zone	50	0
39	6	Kenton	KY 17	Independence	St. Cecelia Elem.	35	16	Zone	15	
40	6	Kenton	US-25-42-127	Covington	St. John's Elem.	35	16	Zone	150	
41*	6	Owen	KY 22 & KY 227	Owenton	Owen Co. H.S. & Elem.	55/50	25/22	Zone	150	25
42*	6	Pendleton	US 27	Falmouth	Pendleton Co. H.S.	55/50	25/22	Zone	0	15
43	6	Pendleton	US 27	Falmouth	Southern Elem.	35	16	Zone	50	
44	6	Robertson	US 62	Mt. Olivet	Deming H.S. & Elem.	35	16	Zone	100	8
45*	7	Anderson	US 127 N. Main	Lawrenceburg	Lawrenceburg Jr. H.S.	35	16	Zone	200	20
46	7	Anderson	US 127 Alton-Frankfort	Alton	Alton Elem.	45	20	Zone	75	20
47	7	Bourbon	US 68 E. Main	Millersburg	Millersburg Elem.	35	16	Zone	150	
48	7	Bourbon	US 27 8th St.	Paris	Paris H.S.	35	16	Crossing	200	
49*	7	Bourbon	US 27-68 Main St.	Paris	St. Mary Elem.	25	11	Zone	150	10
50*	7	Bourbon	US 27-68 High St.	Paris	St. Mary Elem.	35	16	Zone	150	10
51*	7	Bourbon	US 27-68 Lex. Rd.	Paris	Southside Jr. H.S.	35	16	Zone	200	20
52	7	Boyle	US 127 Maple Ave.	Danville	Edna L. Tolliver Elem.	35	16	Zone	200	20
53	7	Boyle	US 150 Stanford Ave.	Danville	Danville Boys Jr. H.S.	35	16	Zone	300	10
54	7	Clark	US 60 N. Main	Winchester	Fannie Bush Elem.	35	16	Zone	200	20
55	7	Clark	US 60 Mt. Sterling Rd.	Winchester	Wm G. Conkwright Jr. H.S., Central Elem.	45	20	Zone	200	40
56	7	Clark	KY 627 Maple Ave.	Winchester	Fannie Bush Elem.	45	20	Zone	100	
57	7	Clark	KY 974 S. Main	Winchester	St. Agatha Academy	35	16	Zone	50	
58	7	Clark	KY 1927 Colby Rd.	Winchester	Hannah McClure Elem.	35	16	Zone	200	20
59*	7	Fayette	US 68 S.	Lexington	Picadome Elem.	40	18	Zone	400	30

LISTING OF INSPECTED SCHOOL FLASHERS

REFERENCE NUMBER	DISTRICT	COUNTY	ROUTE	LOCATION	SCHOOL	EXISTING SPEED LIMIT (mph)	EXISTING SPEED LIMIT (m/s)	SCHOOL ZONE OR CROSSING	ESTIMATED PEDESTRIAN ADT	ESTIMATED BUS ADT
60*	7	Fayette	Broadway KY 1974 Tates Creek	Lexington	Morton Jr. H.S.	45	20	Zone	400	30
61	7	Fayette	US 27-68 N. Bdwy.	Lexington	Mary Todd Elem.	35	16	Crossing	100	
62	7	Fayette	US 25 Gtwn. St.	Lexington	B.T. Washington Elem.	35	16	Crossing	100	
63	7	Fayette	US 25 Niwn Est.	Lexington	Douglas Elem.	35	16	Crossing	100	
64	7	Fayette	KY 418 Athens-Boonesboro	Athens	Athens Elem.	35	16	Crossing	150	20
65*	7	Garrard	US 27 Lex. St.	Lancaster	Lancaster Elem.	35	16	Zone	200	20
66	7	Jessamine	KY 29 Maple St.	Nicholasville	Nicholasville Elem.	35	16	Zone	400	40
67	7	Jessamine	KY 29 Russell Cross Rd.	Nicholasville	Warner Elem. & Jr. H.S.	45	20	Zone	100	40
68*	7	Jessamine	KY 29 S. Lex. St.	Wilmore	Wilmore Elem.	35	16	Zone	200	20
69	7	Madison	US 25-421 W. Main st	Richmond	Bellevue Elem.	35	16	Zone	100	
70	7	Madison	US 24-421 W. Main st Parrish	Richmond	None	35	16	Crossing	100	
71*	7	Madison	US 25-421 Big Hill Ave.	Richmond	Mayfield Elem.	35	16	Zone	100	20
72	7	Madison	E. Main	Richmond	Richmond Elem.	35	16	Zone	200	
73	7	Madison	KY 52 Lancaster Ave.	Richmond	Eastern Ky. Univ.	35	16	Zone	200	None
74*	7	Madison	KY 545 N. Main	Berea	Berea Community Elem. & H.S.	35	16	Zone	300	30
75	7	Madison	KY 545	Kirksville	Kirksville Elem.	35	16	Zone	100	20
76*	7	Mercer	US 68 Lex. Ave.	Harrodsburg	Evan Harlow Elem.	35	16	Zone	200	30
77	7	Mercer	US 68 Perryville Rd.	Harrodsburg	Harrodsburg Elem., J.H., and H.S.	45	20	Zone	100	15
78*	7	Mercer	KY 152 Moreland Ave.	Harrodsburg	Evan Harlow Elem.	35	16	Zone	200	30
79	7	Mercer	KY 152 Main St.	Burgin	Burgin Elem.	35	16	Zone	200	15
80	7	Scott	US 227 Main St.	Stamping Ground	Stamping Ground Elem.	35	16	Zone	200	10
81*	7	Woodford	KY 33 S. Main St.	Versailles	Versailles Elem.	35	16	Zone	200	20
82*	7	Woodford	US 62 Tyrone Rd.	Versailles	Simmons Elem.	45	20	Zone	20	30
83*	7	Woodford	US 62 Frankfort Rd.	Versailles	Woodford Co. H.S.	45	20	Zone	300	40
84	7	Woodford	US 60 Lex. Rd.	Versailles	Versailles Jr. H.S.	35	16	Zone	100	40
85	7	Woodford	US 62 Versailles Rd.	Midway	Midway Elem.	45	20	Zone	150	20
86*	9	Bath	US 60	Owingsville	Owingsville Elem.	35	16	Zone	60	5
87*	9	Bath	KY 211	Salt Lick	Salt Lick Elem.	35	16	Zone	70	3
88*	9	Boyd	US 23 10th & Winchester	Ashland	Ashland Catholic School	35	16	Zone	125	0
89*	9	Boyd	KY 168 Lincoln Ave.	Ashland	Ashland Hager Elem.	20	9	Zone	100	0
90	9	Boyd	KY 168	Ashland	Ashland Oakview Elem.	20	9	Zone	100	0
91*	9	Boyd	KY 180	Cannonsburg	Boyd Co. H.S.	35	16	Zone	50	20
92	9	Boyd	US 23	Catlettsburg	Catlettsburg H.S.	35	16	Zone	100	6
93	9	Boyd	US 23	Catlettsburg	Catlettsburg Yost School	35	16	Zone	50	2
94*	9	Boyd	KY 716	Summit	Summit Elem.	35	16	Zone	110	6
95	9	Boyd	US 23		Cooper Elem.	55	25	Zone	15	5
96*	9	Boyd	US 23		Durbin Elem. School	55	25	Zone	30	4
97	9	Boyd	KY 168	Ashland	Putnam Jr. H.S.	20	9	Zone	75	0
98	9	Carter	US 60	Grayson	Grayson Elem.	35	16	Zone	150	8
99	9	Carter	US 60	Olive Hill	West Carter H.S.	25	11	Zone	300	10
100*	9	Elliott	KY 7	Sandy Hook	Sandy Hook H.S. & Grade School	25/35	11/16	Zone	70	4
101*	9	Fleming	KY 11	Flemingsburg	Fleming Co. H.S.	35	16	Zone	130	8
102*	9	Fleming	KY 32		Fox Valley Elem.	55	25	Zone	20	4
103*	9	Fleming	KY 111	Hillsboro	Hillsboro Elem.	35	16	Zone	40	3
104	9	Greenup	US 23 Bus.	Russell	Russell Elem.	25	11	Zone	100	4
105	9	Greenup	KY 5	Bellefonte	Bellefonte Elem.	35	16	Zone	100	2
106	9	Greenup	KY 207	Flatwoods	Flatwoods Elem.	35	16	Zone	100	6
107	9	Greenup	KY 750	Flatwoods	McDowell Elem.	35	16	Crossing	100	12
108*	9	Greenup	US 23	Raceland	Raceland Elem. & H.S.	25/35	11/16	Zone	150	4
109	9	Greenup	KY 410	E. Main St. Greenup	Greenup Co. H.S.	35	16	Zone	150	8
110*	9	Greenup	US 23		Greys Branch Elem.	55	25	Zone	50	6
111	9	Greenup	US 23		McKell Schools	50	22	Zone	75	12
112*	9	Greenup	KY 7	South Shore	Sunshine Elem.	35	16	Zone	75	3
113	9	Greenup	KY 10	South Portsmouth	S. Portsmouth Elem.	45	20	Crossing	50	6
114	9	Lewis	KY 10	Garrison	Garrison Elem.	35	16	Zone	85	5
115	9	Lewis	KY 57	Tollesboro	Tollesboro H.S.	35	16	Zone	90	7
116*	9	Mason	US 68 & US 62		Mason Co. H.S. & Elem.	45	20	Zone	75	20
117	9	Mason	US 68-62 KY 11	Maysville	Maysville Jr. H.	35	16	Zone	150	3
118	9	Mason	KY 10 Forest Ave.	Maysville	Woodleigh Elem.	35	16	Zone	125	3
119*	9	Nicholas	KY 32-36	Carlisle	Nicholas Co. H.S. & Elem. School	35	16	Zone	50	7
120*	9	Rowan	KY 32	Morehead	Rowan Co. H.S.	35	16	Zone	200	10

*Speed Study

APPENDIX E

EFFECT OF VOLUME CHANGES ON SPEED REDUCTION

Figure E1. Speed-Volume Relationships on Multilane Rural Highways *(12)*.

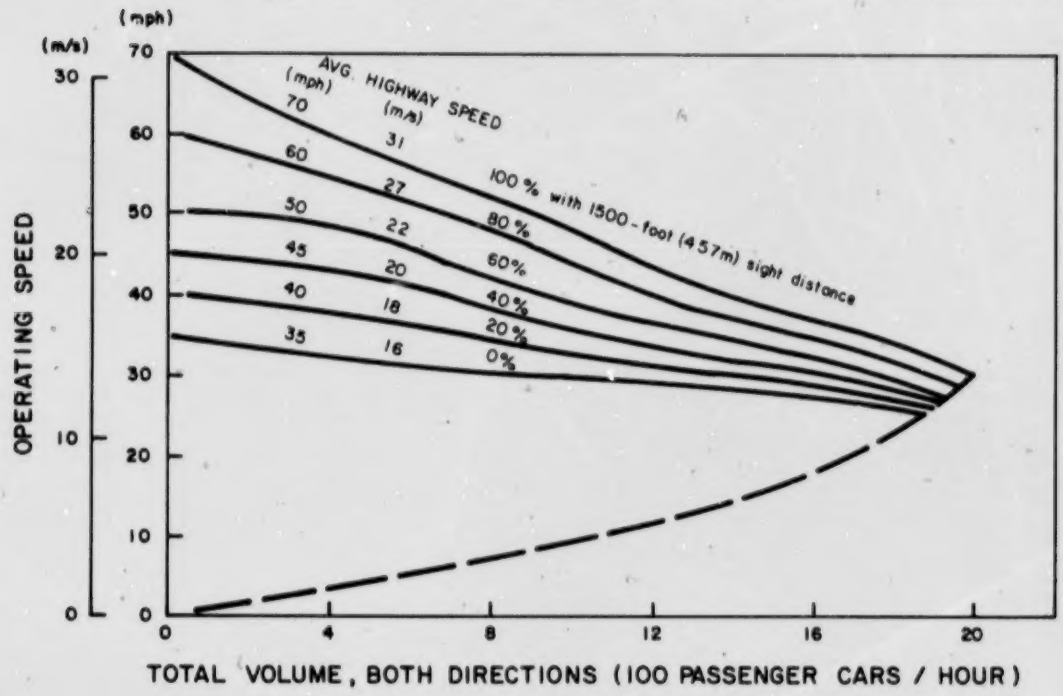

Figure E2. Speed-Volume Relationships on Two-Lane Rural Highways *(12)*.

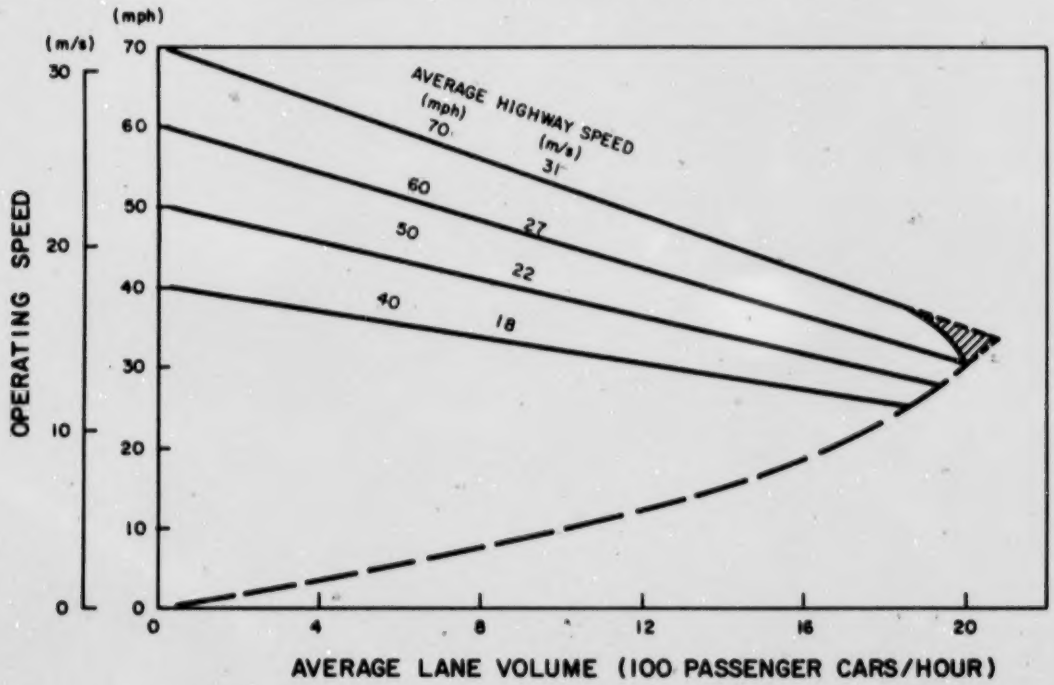

TABLE E1. SPEED REDUCTION DUE TO VOLUME INCREASE

LOCATION NUMBER	POSTED SPEED LIMIT (mph)	POSTED SPEED LIMIT (m/s)	NUMBER OF LANES	VOLUME (VEHICLES PER HOUR) BEFORE FLASHING	VOLUME (VEHICLES PER HOUR) DURING FLASHING	SPEED REDUCTION WHILE FLASHING DUE TO VOLUME CHANGE (mph)	SPEED REDUCTION WHILE FLASHING DUE TO VOLUME CHANGE (m/s)	TOTAL (mph)	TOTAL (m/s)
3	55	25	2	100	170	0.0	0.0	6.8	3.0
8	55	25	2	288	330	0.5	0.2	2.6	1.2
12	40	18	4	504 (126)*	546 (139)*	0.0	0.0	11.1	5.0
25	55	25	2	264	300	0.5	0.2	4.3	1.9
31	45	20	2	200	410	1.5	0.7	7.7	3.4
32	55	25	2	140	270	1.0	0.4	11.8	5.3
37	35	16	2	290	550	2.0	0.9	4.8	2.1
42	55	25	2	130	370	2.5	1.1	8.8	3.9
76	35, 45	16, 20	2	240	260	0.0	0.0	2.2	1.0
82	45	20	2	290	280	0.0	0.0	0.5	0.2
96	55	25	2	780	906	2.5	1.1	2.6	1.2
102	55	25	2	136	104	0.0	0.0	7.2	3.2
108	25, 45	11, 20	2	480	582	0.5	0.2	9.1	4.1
110	55	25	2	186	324	1.5	0.7	0.5	0.2
112	35	16	2	196	256	0.0	0.0	5.2	2.3
116	45	20	2	756	786	0.0	0.0	3.8	1.7
Average	48	21				0.8	0.4	5.6	2.5

*Vehicles per Lane

APPENDIX F

STATISTICAL TESTS

A statistical analysis was made of the 54 speed studies taken at 48 locations to determine whether the speed reductions during the flashing period could be attributed to the flasher with a 95-percent certainty. If this could not be shown for a particular location, the speed reduction would be attributed to chance variation. The percentage of flashers which cause a statistically significant reduction in vehicle speeds (with 95-percent probability) can be determined.

Because of variations in traffic volumes at the locations, the sample size for speed studies "before flashing" ranged from 57 to 650 vehicles for the sample period. With limited flashing time at some locations, the sample size "during flashing" ranged from 31 to 575 vehicles. A sample of at least 100 was taken for each period, whenever possible, and was achieved in over 70 percent of the speed samples. For each speed study, the average speed was computed before flashing ($\bar{x}_1$) and during flashing ($\bar{x}_2$). The sample size was recorded for the before-flashing (n_1) and during-flashing (n_2) periods. The standard deviations were determined for both periods (σ_1 and σ_2). The formula *(13)* used for computation of standard deviations was:

$$\sigma = \sqrt{\Sigma f (v - \bar{x})^2/(n - 1)}$$

where σ = standard deviation of the speed sample,
$\bar{x}$ = average speed of the sample,
f = number of vehicles observed at each speed (v), and
n = sample size.

In using the standard deviation formula, each sample was assumed to be a normal distribution.

When a normal approximation is used for a speed sample and $n \geq 30$ for $\bar{x}_1$ and $\bar{x}_2$, the value $(\bar{x}_1 - \bar{x}_2)$ is asymptotically normal with a mean of zero and a standard deviation of σ_D *(13)* where $\sigma_D = \sqrt{(\sigma_1^2/n_1) + (\sigma_2^2/n_2)}$. This statement holds true if the average speeds of the vehicles before flashing ($\bar{x}_1$) and while flashing ($\bar{x}_2$) represent no significant difference in vehicle population. This is a reasonably good assumption since both parts of the study before and during flashing were taken within about a 2-hour period on the same day. Using the properties of a normal distribution *(13)*, it is with a 95-percent probability that

$$\bar{x}_1 - \bar{x}_2 = 0 \pm 1.645\ \sigma_D.$$

If the speed reduction due to the school flasher ($\bar{x}_1 - \bar{x}_2$) is larger than $1.645\ \sigma_D$, then the flasher has caused a significant reduction in speed (with 95-percent certainty). Also in this case, it is at most five percent probable that the speed reduction occurred by chance *(13)*.

In each of the 54 speed studies, the values of $1.645\ \sigma_D$ were compared to actual speed differences $(\bar{x}_1 - \bar{x}_2)$ to determine whether the speed reduction was statistically significant. Without considering the five studies where crossing guards were present during flashing, the school flashers alone caused a statistically significant vehicle speed reduction in 41 of 49, or about 84 percent, of the locations tested. The test of a 99-percent significance level (using $2.326\ \sigma_D$) yielded 36 of 49, or 73 percent, of the locations having statistically significant speed reductions due to the flashing beacons. A detailed listing of values in each statistical analysis is given in Table E1 for specific location numbers (corresponding to the numbers in APPENDIX A).

TABLE F1. STATISTICAL ANALYSIS OF SPEED STUDIES

LOCATION NUMBER	n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2	σ_D	$1.645\sigma_D$	$\bar{x}_1-\bar{x}_2$	95 PERCENT SIGNIFICANCE
2	300	42.1	4.73	240	35.0	4.89	0.42	0.69	7.1	Yes
3	65	48.9	5.75	70	42.1	5.31	0.95	1.56	6.8	Yes
4	175	34.4	4.39	100	30.8	3.86	0.51	0.84	3.6	Yes
5	84	28.4	6.26	106	27.5	6.27	0.92	1.51	0.9	No
6	100	33.2	5.81	98	34.0	6.42	0.87	1.42	-0.8	No
8	117	47.9	5.04	108	45.3	5.76	0.72	1.19	2.6	Yes
12	132	45.1	6.55	110	34.0	6.31	0.83	1.36	11.1	Yes
13	65	36.4	5.41	70	27.1	5.42	0.93	1.53	9.3	Yes
18	185	42.5	6.45	225	40.5	7.46	0.69	1.14	2.0	Yes
25	103	51.4	5.18	117	47.1	5.82	0.74	1.22	4.3	Yes
29	650	37.2	3.36	575	34.7	4.08	0.22	0.36	2.5	Yes
31	75	39.2	6.32	125	31.5	6.11	0.91	1.50	7.7	Yes
32	75	48.9	6.27	80	37.1	6.45	1.02	1.68	11.8	Yes
37	150	36.1	4.51	110	31.2	4.48	0.48	0.79	4.8	Yes
41	68	34.5	6.68	70	33.6	7.90	1.24	2.04	0.9	No
42	85	48.2	5.46	135	39.4	7.73	0.89	1.46	8.8	Yes
45	105	32.7	6.15	109	30.4	6.34	0.85	1.40	2.3	Yes
49	103	32.0	6.15	111	30.1	5.54	0.80	1.32	1.9	Yes
50	200	28.5	5.69	249	27.8	4.97	0.51	0.84	0.7	No
50*	103	32.0	6.15	86	28.7	4.47	0.77	1.27	3.3	Yes
51	102	28.2	6.30	100	22.9	3.91	0.74	1.22	5.3	Yes
59	111	34.8	4.87	121	32.4	4.32	0.61	1.00	2.4	Yes
60	110	31.6	3.95	111	25.5	3.69	0.51	0.84	6.1	Yes
65	375	29.7	4.65	476	28.4	4.83	0.33	0.54	1.3	Yes
65	323	29.3	4.42	342	27.8	4.50	0.35	0.57	1.5	Yes
68	90	30.9	4.34	31	28.4	4.49	0.93	1.53	2.5	Yes
68*	90	30.9	4.34	65	22.8	3.92	0.67	1.10	8.1	Yes
71	109	31.1	5.29	114	28.2	5.63	0.73	1.20	2.9	Yes
74	126	38.6	6.46	115	35.9	5.49	0.77	1.27	2.7	Yes
76	112	38.1	6.93	209	35.9	7.18	0.82	1.35	2.2	Yes
78	95	31.8	5.48	112	29.3	5.17	0.74	1.22	2.5	Yes
81	137	31.5	5.54	113	28.6	6.20	0.75	1.22	2.9	Yes
81*	137	31.5	5.54	32	19.4	5.63	1.10	1.81	12.1	Yes
82	107	36.2	7.27	131	35.7	6.35	0.90	1.48	0.5	No
83	146	30.0	6.16	147	26.3	6.13	0.72	1.18	3.7	Yes
86	103	31.7	6.19	103	29.1	4.61	0.76	1.25	2.7	Yes
87	96	33.6	5.28	86	31.9	5.83	0.82	1.35	1.7	Yes
88	99	28.2	6.77	101	27.6	6.48	0.94	1.54	0.6	No
89	115	29.5	5.11	99	26.5	5.35	0.72	1.18	3.0	Yes
91	109	40.6	8.95	125	38.5	8.20	1.13	1.85	2.1	Yes
94	107	33.5	6.58	102	31.6	6.69	0.92	1.51	1.9	Yes
96	130	50.9	6.55	129	48.3	6.69	0.82	1.35	2.6	Yes
100	102	36.2	7.33	103	35.9	6.99	1.00	1.65	0.3	No
101	100	34.5	4.18	61	31.4	3.61	0.62	1.02	3.1	Yes
101*	100	34.5	4.18	94	24.5	4.40	0.50	0.82	10.0	Yes
102	100	49.3	7.55	79	42.1	9.15	1.28	2.11	7.2	Yes
103	100	38.5	5.95	88	36.6	5.84	0.86	1.41	1.9	Yes
108	103	40.8	7.39	113	31.7	6.90	0.98	1.60	9.1	Yes
110	104	52.8	6.36	99	52.3	6.50	0.90	1.49	0.5	No
112	106	37.5	7.53	106	32.3	6.45	0.96	1.58	5.2	Yes
116	102	42.8	5.03	100	39.1	6.24	0.80	1.32	3.8	Yes
119	57	32.8	3.47	107	31.8	3.70	0.58	0.95	1.0	Yes
120	102	34.2	6.06	94	30.8	5.17	0.80	1.32	3.4	Yes
120*	102	34.2	6.06	84	23.1	3.22	0.70	1.15	11.1	Yes

*Crossing Guard Present